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BLOCKAGE STUDY OF A 1/16-SCALE B-1 INLET MODEL IN THE 1-FT TRANSONIC AND SUPERSONIC TUNNELS OF THE PROPULSION WIND TUNNEL FACILITY

C. F. Anderson and F. M. Jackson

ARO, Inc.

October 1972

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PROPULSION WIND TUNNEL FACILITY

ARNOLD ENGINEERING DEVELOPMENT CENTER

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NOTICES

BLOCKAGE STUDY OF A 1/16-SCALE B-1 INLET MODEL IN THE 1-FT TRANSONIC AND SUPERSONIC TUNNELS OF THE PROPULSION WIND TUNNEL FACILITY

C. F. Anderson and F. M. Jackson

ARO, Inc.

FOREWORD

The work reported herein was done at the request of the Aeronautical Systems Division (ASD), Air Force Systems Command (AFSC), for North American Rockwell Corporation, Los Angeles, California, under Program Element 66215F, System 139A, Task 01A.

The test results presented were obtained by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of the Arnold Engineering Development Center (AEDC), AFSC, Arnold Air Force Station, Tennessee, under Contract F40600-73-C-0004. The tests were conducted from December 7, 1971, through June 19, 1972, under ARO Project No. PT0247. The manuscript was submitted for publication on August 24, 1972.

This technical report has been reviewed and is approved.

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ABSTRACT

Tests were conducted in the 1-ft Aerodynamic Wind Tunnels (1T and 1S) of the Propulsion Wind Tunnel Facility to obtain estimates of the performance available for the full-scale B-1 inlet/engine tests in the 16-ft Propulsion Wind Tunnels (16T and 16S). Data were obtained with two nacelle configurations and four wing configurations. The maximum test section blockage was 17 percent. Data were obtained at Mach numbers from 0.55 to 1.30 and from 1.71 to 2.30. The tunnel performance for each configuration was evaluated relative to the others and with regard to the capabilities of the 16-ft tunnels. The results of these tests indicate that the available tunnel performance is significantly compromised with the nacelle configuration which has been selected for the full-scale test. The maximum Mach number estimated to be available for the full-scale test in Tunnel 16T is 1.0. To obtain a full range of engine operating points, however, testing should be restricted to $M \leq 0.90$. The estimated starting and operating pressure ratio requirements for the full-scale B-1 test are within the Tunnel 16S capability. The minimum starting Mach number estimated to be available for the full-scale B-1 test in Tunnel 16S is 1.96. The minimum operating Mach numbers estimated to be available for the full-scale test are 1.83 at full inlet airflow and 1.88 at windmill airflow.

CONTENTS

APPENDIXES

I. ILLUSTRATIONS

NOMENCLATURE

DCN	Diffuser contour number
DFO	Diffuser flap opening, in.
M_∞	Free-stream Mach number
p	Tunnel wall static pressure, psfa
p_T	Free-stream total pressure, psfa
W_A	Measured auxiliary weight flow, lb/sec
W_C	Theoretical inlet capture weight flow, lb/sec
W_E	Measured scavenging scoop weight flow, lb/sec
W_T	Theoretical one-dimensional tunnel weight flow, lb/sec
α	Wing angle of attack, deg
θ_W	Angle of test section top and bottom walls (positive when diverged), min

λ Tunnel pressure ratio (ratio of stilling chamber total pressure to diffuser exit pressure)

λ^* Tunnel 1T nominal operating pressure ratio

ϕ Diffuser area ratio (area of the diffuser at Jack Station 2 ratioed to the area of the test section at zero wall angle)

$\mathfrak{Z}$ Minimum diffuser area ratio or minimum Mach number for starting or operating

SECTION I
INTRODUCTION

The B-1 is a low, variable geometry wing aircraft with a midposition tail and is powered by four General Electric F101 engines. The B-1 wind tunnel program includes extensive inlet development testing with small-scale models of the air vehicle inlet. Plans also include the testing of a full-scale inlet-engine system in the 16-ft Propulsion Wind Tunnels (16T and 16S) at the Arnold Engineering Development Center. The feasibility of such a test program has been documented by the successful conduct of full-scale tests of the B-70, F-111, and F-15 inlet/engine systems in the PWT 16-ft tunnels.

The performance available in the 16-ft tunnels varies as a function of the test section blockage created by the model installation. Various blockage studies with models with blockages ranging from about 13 to 21 percent (Refs. 1 through 4) have been conducted in the 1-ft Aerodynamic Wind Tunnels (1T and 1S) of the Propulsion Wind Tunnel Facility. The results of these tests indicate that available tunnel performance is dependent not only upon blockage but upon the peculiarities of the specific model installation. In addition these tests indicate that in the 16-ft tunnels a reasonable test rhombus can be obtained up to a maximum model blockage of approximately 18 percent.

The preliminary design efforts for the B-1 full-scale test article were based on a maximum blockage of about 17 percent. To verify test feasibility and to determine the effects of blockage on available tunnel performance a blockage test using a 1/16-scale B-1 inlet was conducted in the 1-ft Aerodynamic Wind Tunnels (1T and 1S) of the Propulsion Wind Tunnel Facility. The results of this investigation are presented in this report.

Data were obtained at Mach numbers from 0.55 to 1.30 in Tunnel 1T and at Mach numbers from 1.71 to 2.30 in Tunnel 1S. The effects of various tunnel parameters, model attitude, wing configuration, and engine bypass airflow were evaluated. During the conduct of the blockage tests, several changes in the design of the full-scale test model were made. Consequently, the blockage model was modified to more closely simulate the altered design of the full-scale test installation, and therefore, two nacelle configurations were tested in Tunnel 1S.

The 1/16-scale test results will be used to evaluate the relative effects of various tunnel and model parameters upon tunnel performance and to obtain preliminary estimates of the performance available in Tunnels 16T and 16S for the full-scale B-1 inlet/engine test. Final estimates of the performance of Tunnels 16T and 16S for the full-scale B-1 test are not presently possible, as a thorough analysis of the full-scale test installation and the operating characteristics of the B-1 test engine, as well as the operating characteristics of the 16-ft tunnels, is required.

SECTION II
APPARATUS

2.1 TEST FACILITIES

2.1.1 Tunnel 1T

Tunnel 1T is a continuous-flow, nonreturn wind tunnel capable of operating at Mach numbers from 0.2 to 1.5, utilizing variable nozzle contours above $M_\infty = 1.1$. The tunnel is operated at a stilling chamber total pressure of about 2850 psfa with a ±5-percent variation dependent on tunnel resistance and ambient atmospheric conditions. The stagnation temperature can be varied from 80 to 120°F above ambient temperature as necessary to prevent visible condensation in the test section. The test section is 1 ft square and 37.5 in. long, with 6-percent porous perforated walls. The general arrangement of the tunnel and its associated equipment is shown in Fig. 1 (Appendix I), and a schematic of the nozzle, test section, and wall geometry is shown in Fig. 2. A detailed description of the tunnel and its capabilities is given in Ref. 5.

2.1.2 Tunnel 1S

Tunnel 1S is a continuous-flow, nonreturn wind tunnel equipped with a two-dimensional, semiflexible nozzle. The tunnel can be operated within a Mach number range from 1.5 to 5.5 and a stagnation pressure range from 700 to 6500 psfa. The stagnation temperature can be varied from 80 to 180°F throughout the Mach number range. The general arrangement of the tunnel and its associated equipment is shown in Fig. 3, and a schematic of the nozzle, test section, and diffuser is shown in Fig. 4. A detailed description of the tunnel and its capabilities is given in Ref. 5.

2.2 TEST ARTICLE

2.2.1 General

The test article was a 1/16-scale model representing the outboard inlet of the B-1 left-hand dual inlet/engine nacelle. The model was strut supported from the tunnel sidewall and was connected to the tunnel scavenging scoop by means of a flexible exhaust tube assembly. Photographs of typical installations in Tunnels 1T and 1S are shown in Figs. 5 and 6, respectively.

The model lines at the inlet entrance duplicated the full-scale lines. A partial wing was used to simulate the inlet flow field. Removable ramp blocks were used to simulate maximum cowl-lip flow area and various inlet restart ramp schedules. Interchangeable sets of bypass doors were used to provide engine airflow simulation. During the testing in Tunnel 1S the external contour of the nacelle, the ramp geometry, the bypass door configuration, and the mounting strut were modified to more closely simulate the current design of the full-scale test installation. Schematics showing the various model components and the two nacelle configurations which were tested are shown in Figs. 7, 8, and 9. Detailed descriptions of model components and a discussion of model blockage are presented in the following sections of this report.

2.2.2 Model Wings

For the Tunnel 1T test, three wing configurations, as shown in Figs. 7a and b, were available. The basic contoured wing (Fig. 7a) configuration was a partial surface representing the full-scale wing lower surface mold lines ahead of the inlet. The full contoured wing (Fig. 7a) configuration utilized a fairing and the basic wing to extend the contoured surface 1.875 in. inboard. The third configuration was a flat plate partial wing surface with a rounded leading edge (Fig. 7b). In addition to these configurations the nacelle could be tested with the wing removed.

Three wing configurations were also available for Tunnel 1S; prior to testing, however, the flat plate wing was modified to simulate the current full-scale installation. This flat plate wing, which is shown in Fig. 7c, had an increased wing area and a sharp leading edge.

2.2.3 Model Ramps

A simplified ramp arrangement was utilized for the tests with nacelle configuration I. In Tunnel 1S, the ramp block, which is shown in Fig. 8a, simulated the initial ramp angle (10.5 deg) for Mach 2.2 cruise

condition. In Tunnel 1T, a block with a 4-deg initial ramp angle was utilized to provide maximum inlet airflow.

For testing nacelle configuration II in Tunnel 1S, provisions were available for three different ramp geometries, each with 0 and 11 percent porous plates. These ramps, which are illustrated in Fig. 9, simulated Mach 1.8 cruise (Fig. 9a), Mach 2.2 cruise (Fig. 9b), and Mach 2.2 restart (Fig. 9c) conditions.

2.2.4 Model Bypass Doors

Engine bypass airflow simulation was provided by two bypass doors located on the outboard side of the nacelle for the tests with nacelle configuration I. Interchangeable sets of doors were used to provide door openings of 0 (closed), 15, 30, and 45 deg into the airstream. Nacelle configuration II employed a single bypass door arrangement rather than a dual door arrangement. The forward door on the nacelle was modified to a configuration consistent with the current full-scale design. Although the rear door was retained as an auxiliary bypass for the model tests, it was closed for all data obtained with nacelle configuration II.

2.2.5 Model Blockage

The distributions of model blockage in Tunnels 1T and 1S are shown in Figs. 10 and 11. These figures present the ratio of the model cross-sectional area to the tunnel area as a function of tunnel station for zero test section wall angle, inlet airflow, and model attitude. As shown in Figs. 10 and 11, the maximum blockage for both the Tunnel 1T and Tunnel 1S tests was 17 percent. Data were obtained in Tunnels 1T and 1S with the test section wall angle diverged up to 60 min. Test section wall divergence of 60 min decreased the maximum blockage for Tunnels 1T and 1S to 15.8 percent and 16.4 percent, respectively. Although the maximum tunnel blockage was not changed with nacelle configuration II, the strut modification (a 3.85-in. extension) and the nacelle modification caused a significant change in the blockage distribution.

2.3 INSTRUMENTATION

2.3.1 Model Instrumentation

Inlet flow conditions were monitored by the model instrumentation, which included a dynamic pressure transducer located internally on the upper sideplate and pressure orifices located internally on the inlet ramp, lower sideplate, and cowl surfaces. Instrumentation for sensing

model pressures included pressure orifices on the upper and lower wing surfaces and orifices located externally on the nacelle ramp, lower sideplate, and cowl sides. For the testing in Tunnel 1S with nacelle configuration II, pressure orifices on the support strut and instrumentation to sense the inlet and engine face total pressures were also included. Model pressures were measured by and photographically recorded from a mercury manometer board.

Model angle of attack of nacelle configuration I could be varied between -1 and 4 deg through an electrically driven screw-jack actuator. The model position was displayed on a digital voltmeter.

2.3.2 Tunnel 1T Instrumentation

The tunnel plenum chamber pressure was measured by a self-balancing precision manometer. The stilling chamber total pressure, diffuser exit total pressure, and four wall static pressures were measured with differential transducers and displayed on electromanometers. The stilling chamber total pressure, plenum chamber static pressure, diffuser exit total pressure, and several wall static pressures were also measured by and photographically recorded from a mercury manometer board.

The scavenging scoop and plenum airflows were measured by the use of square-edged orifices in the plenum and scavenging scoop lines. The general location of the metering orifices is shown in Fig. 1. The upstream static pressures and the differential pressures across the orifices were measured with differential transducers and displayed on electromanometers. The upstream and downstream static pressures at the orifices were also measured by and photographically recorded from a mercury manometer board.

The tunnel stagnation temperature and orifice airflow temperatures were measured with iron-constantan thermocouples and displayed on indicating, potentiometer-type recorders.

2.3.3 Tunnel 1S Instrumentation

The tunnel stilling chamber pressure and the diffuser exit total pressure were measured with differential transducers and displayed on electromanometers. In addition, these pressures and the static pressure distribution in the nozzle, test section, and diffuser were measured by and photographically recorded from a mercury manometer board.

The scavenging scoop airflow was measured by the use of a square-edged orifice. For the testing with nacelle configuration I the orifice was located in the scavenging line, as shown in Fig. 3. For the testing with nacelle configuration II the orifice was located in the model, as shown in Fig. 8b. The orifice upstream static pressure and differential pressure were measured with differential transducers and displayed on electromanometers and measured by and photographically recorded from a mercury manometer board.

Tunnel stagnation and orifice airflow temperatures were measured with iron-constantan thermocouples and were displayed on a potentiometer-type indicator.

SECTION III
PROCEDURES

3.1 TUNNEL 1T

3.1.1 Test Conditions

Data were obtained with nacelle configuration I over the Mach number range from 0.55 to 1.30. The tunnel stagnation pressure (stilling chamber total pressure) varied from 2800 to 2890 psfa. The stagnation temperature was varied from 140 to 190°F; however, for most runs the temperature was maintained at 150°F.

3.1.2 Test Discussion

Mach numbers in Tunnel 1T were established by setting various combinations of tunnel nozzle contour, pressure ratio, and plenum pressure. Data were obtained at discrete Mach numbers of 0.55, 0.70, 0.85, 0.90, and 1.1, utilizing a sonic nozzle contour. Data at Mach numbers of 1.2 and 1.3 were obtained utilizing contoured nozzle settings. At each Mach number and for specific pressure ratios ranging from 1.10 to 1.40, the plenum pressure, which is controlled by a steam ejector system, was set according to the tunnel calibration reported in Ref. 6. Flow removed through the test section walls by plenum suction is referred to as tunnel auxiliary weight flow in this report.

In addition to the above-mentioned parameters, other tunnel variables which were investigated included the diffuser flap opening and test section wall angle. Data were obtained with diffuser flap positions of 0 and 0.5 in. and at test section wall angles of 0, 30, and 60 min. Positive wall angles indicate wall divergence from the centerline.

The principle test article variables included wing configuration, model attitude, and inlet airflow. Data were obtained with the rounded-edge flat plate, basic contoured, and full contoured wings and with no wing. Data were obtained at model angles of attack from 0 to 3 deg. The inlet airflow was varied from 0.2 to 1.5 lb/sec. Data, however, usually were obtained at either the maximum or minimum airflow attainable at specific tunnel conditions. These airflows were obtained with a full-open and with the leakage past a full-closed scavenging scoop valve.

The objectives of the test included obtaining an estimate of the maximum operating Mach number for the full-scale test in Tunnel 16T. For Tunnel 16T, the maximum operating Mach number is limited by the available tunnel auxiliary weight flow. Consequently, the testing procedure in Tunnel 1T involved defining the auxiliary weight flow requirements for various combinations of tunnel and model variables. The relationship between the auxiliary weight flow requirements for Tunnels 1T and 16T is discussed in Appendix III.

3.2 TUNNEL 1S

3.2.1 Test Conditions

Data were obtained with nacelle configurations I and II over the Mach number range from 1.71 to 2.30 and 1.83 to 2.30, respectively. A stilling total chamber pressure of 2180 psfa and a stagnation temperature of 100°F were maintained for the test.

3.2.2 Test Discussion

Mach numbers in Tunnel 1S were obtained by setting the nozzle to a precalibrated contour and adjusting the tunnel back pressure to establish supersonic flow. Data were obtained at discrete Mach numbers of 1.8, 2.0, 2.2, and 2.3. Other tunnel parameters of interest with respect to tunnel performance were test section wall angle, diffuser area ratio, and tunnel pressure ratio.

Throughout most of the investigation a test section wall angle setting of 30 min was utilized. Limited data, however, were also obtained at wall angles of -30, 0, and 60 min.

The diffuser area ratio, which is defined as the ratio of the area of the diffuser at Jack Station 2 (tunnel station 47.9) to the area of the test section for a wall angle of 0 deg, was varied from 0.82 to 1.047. The

minimum area of the diffuser actually occurs at tunnel station 49.9; however, Jack Station 2 is used as a key in positioning of the diffuser in both Tunnels 1S and 16S. Figure 12 shows the variation of diffuser area ratio with diffuser contour number.

The tunnel pressure ratio is defined as the ratio of the stilling chamber pressure to the diffuser exit pressure. It must be pointed out that the pressure ratios in Tunnel 1S do not directly apply to Tunnel 16S. The differences are discussed in Appendix III.

The principle test article variables included nacelle configuration, wing configuration, model attitude, inlet airflow, inlet ramp position, and bypass door position. With nacelle configuration I, data were obtained with the sharp-edged flat plate, basic contoured, and full contoured wings. With nacelle configuration II, data were obtained only with the sharp-edged flat plate wing. Data were obtained at model angles of attack of 0 and 3.0 deg with nacelle configuration I and 2.7 deg with nacelle configuration II. The inlet airflow was varied from 0.1 to 1.1 lb/sec. Data were obtained with the scoop flow control valve open and throttled to obtain full and reduced inlet airflows. Data were obtained for the various ramp and bypass positions, as discussed in Section 2.2.

The objectives of this test included obtaining an estimate of minimum operating Mach number and the tunnel starting and operating capability for the full-scale test in Tunnel 16S. For Tunnel 16S, the minimum operating and starting Mach numbers depend upon model blockage, and the starting and operating performance is limited by the available tunnel pressure ratio. Consequently, the testing procedure in Tunnel 1S was to utilize on-line nozzle movements to determine the minimum starting and operating Mach number for combinations of the various test variables. The tunnel starting and operating performance was defined by modulating a tunnel control valve to increase or decrease the tunnel pressure ratio to obtain flow starts or unstarts at various combinations of the test variables. Minimum diffuser area ratios for starting and operating were also defined.

3.3 DATA REDUCTION AND ACCURACY

The manometer board data were photographically recorded and reduced by an off-line computer program used in conjunction with semiautomatic film reading equipment. In Tunnel 1T, the outputs of the self-balancing precision manometer, the transducers, and the thermocouple were converted to digital form and recorded on paper tape for off-line data reduction. In Tunnel 1S, all data except the manometer data were entered into the computer program from hand-recorded inputs.

The probable errors associated with the tunnel and model parameters are:

DFO	±0.02 in.
M_∞	±0.01 Tunnel 1T
	±0.02 Tunnel 1S
W_A	±10 percent
W_E	±10 percent
α	±0.10 deg
θ_W	±2 min
λ	±0.05
ϕ	±0.02

The error in free-stream Mach number was determined from longitudinal pressure distributions and is based on a 95-percent confidence level. The errors associated with other data presented in this report were estimated from single sample measurements based on the accuracy of the instrumentation.

SECTION IV
RESULTS AND DISCUSSION

4.1 TUNNEL 1T

4.1.1 General

The maximum Mach number that can be obtained in Tunnel 16T with a large blockage model is limited by the capacity of the auxiliary flow system. The discussion of the Tunnel 1T results deals with defining the effects of variation of tunnel and model parameters upon the auxiliary weight flow requirements. In addition, the data are utilized to obtain an estimate of the maximum operating Mach number for the full-scale test in Tunnel 16T.

For data presentation, the auxiliary weight flows are normalized by a theoretical one-dimensional tunnel weight flow. The auxiliary flow available in Tunnel 16T is discussed in Appendix III. Because of the similarities of data trends, data for only some of the possible combinations of all tunnel and model parameters were obtained. In addition,

only those data which are considered sufficient to satisfy the objectives of this test are presented herein.

4.1.2 Effects of Tunnel Parameters

The discussion in this section of the report pertains to the effects of variation of tunnel pressure ratio, test section wall angle, and diffuser flap position upon the auxiliary weight flow requirements. All of the data presented are for maximum inlet airflow (i. e., scavenging scoop valve fully open) and α = 3. 0 deg.

The effect of tunnel pressure ratio variation at θ_W = 60 min and DFO = 0 in. for the flat plate and basic contoured wings is presented in Fig. 13. The reason for the dashed fairings between Mach 1. 1 and 1. 2 is that data at 1. 2 and above were obtained with a supersonic nozzle contour, whereas a sonic nozzle contour was utilized for $M_\infty \leq 1.1$. Data presented in Ref. 3 indicate that between Mach 1. 1 and 1. 2 utilization of nozzle contours has less than a 5-percent effect upon the auxiliary weight flow. The data presented in Fig. 13 indicate that, in general, the auxiliary weight flow requirements decrease with increase in tunnel pressure ratio and that this effect is not as significant for $\lambda \geq 1.30$. In Tunnel 16T, the maximum available pressure ratio is limited by the tunnel compressor system performance and/or test altitude requirements. Data presented in Refs. 7 and 8 indicate that at each Mach number there is an optimum tradeoff between auxiliary suction and tunnel pressure ratio. In addition, both the auxiliary suction and pressure ratio requirements increase with model blockage. These factors determine the operating pressure ratio for each Mach number. An estimate of the operating pressure ratios for the full-scale test is given in Table I, Appendix II.

The effect of test section wall angle variation at DFO = 0 and $\lambda = \lambda^*$ is presented in Fig. 14. In order to show the relative effects of other test variables, a nominal Tunnel 1T pressure ratio schedule, λ^*, was selected. This schedule (λ^*), which is based on the Tunnel 16T estimated operating pressure ratios, and the pressure ratios utilized during this test are shown in Table I. Sufficient data were available at Mach numbers 0. 85 and 0. 90 so that linear interpolation provided good results. When the wall was set at 0 deg, supersonic operation could not be achieved with the maximum pressure ratio and auxiliary airflow available in Tunnel 1T. The data in Fig. 14 indicate that the auxiliary weight flow requirements decrease with increasing test section wall angle divergence and that θ_W = 60 min should be utilized for the full-scale test in Tunnel 16T.

The effect of diffuser flap position variation at $\lambda = \lambda^*$ and $\theta_W = 60$ min is presented in Fig. 15. The data in Fig. 15 indicate that opening the diffuser flaps decreases the auxiliary flow requirements. Because of the changes in full-scale test hardware which were made after the Tunnel 1T tests and the fact that the 1/16-scale model did not simulate the full-scale scavenging scoop assembly, it is anticipated that the diffuser flap opening in Tunnel 16T may not be as effective as that shown in Fig. 15. Therefore, for estimation of the maximum operating Mach number available in Tunnel 16T, results for the closed diffuser flap position are utilized.

4.1.3 Effects of Model Parameters

The discussion in this section of the report pertains to the effects of variation of wing configuration, model attitude, and inlet airflow upon the auxiliary weight flow requirements. All of the data presented are with $\lambda = \lambda^*$, $\theta_W = 60$ min, and DFO = 0 in.

The effect of wing configuration variation at $\alpha = 3.0$ deg and maximum inlet airflow is presented in Fig. 16. The data in Fig. 16 indicate that the full contoured wing required the maximum auxiliary weight flow, particularly at $M_\infty < 0.9$. The data also indicate that because the basic contoured wing required the minimum auxiliary weight flow in the Mach number range from 0.8 to 1.1 it would provide the best tunnel performance for the full-scale tests. Because of structural considerations, however, the full-scale test hardware has been designed with a flat plate wing which, incidentally, differs from that tested in Tunnel 1T. The 1/16-scale flat plate wing was modified after the model was removed from Tunnel 1T. Because the data which had been obtained (Fig. 16) indicated that wing configuration did not have a significant effect upon auxiliary weight flow requirements at supersonic Mach numbers, the modified flat plate wing was not tested in Tunnel 1T. For estimation of the maximum operating Mach number available in Tunnel 16T, the flat plate wing data are utilized.

The effect of model attitude variation with the flat plate wing and maximum inlet airflow is presented in Fig. 17. The data in Fig. 17 indicate that the variation of auxiliary weight flow over the model attitude range from 0 to 3.0 deg is not significant.

The effect of inlet airflow variation with the flat plate wing and $\alpha = 3.0$ deg is presented in Fig. 18. The data in Fig. 18 indicate that reducing the inlet airflow increases the auxiliary weight flow requirements significantly at all Mach numbers. Because the full-scale engine operating characteristics are not completely defined, the data for mini-

mum and maximum airflows are utilized to obtain an estimate of the range of operations available in Tunnel 16T for various engine operating points.

4.1.4 Summary of Tunnel 1T Results

The evaluation of the effects of the various tunnel and model variables upon auxiliary weight flow requirements has been presented in the preceding sections of this discussion. In this summary an estimation of the maximum operating Mach number available for the full-scale tests in Tunnel 16T is presented. The Tunnel 16T performance estimate is based on the Tunnel 1T data obtained at θ_W = 60 min, DFO = 0 for $\lambda = \lambda^*$ with the flat plate wing, α = 3.0 deg and with both minimum and maximum inlet airflows.

The auxiliary weight flow requirements and an estimate of the auxiliary weight flow capacity which would be available for recommended and minimum altitudes in Tunnel 16T for the full-scale test are presented in Fig. 19. The auxiliary weight flow available in Tunnel 16T and the relationship of this parameter between Tunnels 16T and 1T are discussed in Appendix III. As indicated in Appendix III, data obtained in Tunnel 1T underestimate the Tunnel 16T auxiliary flow requirements. Accordingly, the Tunnel 1T results, presented in Fig. 19, were increased by 60 percent to account for the difference in tunnel performance. The data in Fig. 19 indicate that for maximum inlet airflow the maximum operating Mach number available in Tunnel 16T is 1.0. For minimum inlet airflow the maximum operating Mach number is 0.90 and 0.98 for the minimum and recommended altitudes, respectively. An important consideration for the full-scale test is the tunnel performance at engine windmill airflow. The data presented for minimum inlet airflow is considered to provide a conservative estimate of the engine windmill airflow requirements. To be able to obtain a full range of engine operating points considering the current design of the full-scale test nacelle, it is estimated that testing in Tunnel 16T may be restricted to $M_\infty \leq 0.90$.

4.2 TUNNEL 1S

4.2.1 General

The minimum Mach numbers at which Tunnel 16S can be started and operated for the full-scale test are dependent upon the model blockage. The minimum Mach number for which flow could be maintained was determined by increasing the nozzle area at a maximum diffuser area ratio and tunnel pressure ratio until the test section choked, causing a flow

unstart. The minimum Mach number for which test section flow could be started was determined by providing sufficient tunnel pressure ratio at a starting diffuser area ratio and decreasing the nozzle area until flow started.

The performance of Tunnel 16S is considered to be sufficiently described if the diffuser area ratios and tunnel pressure ratios for which the tunnel can be started and operated at various Mach numbers are determined. The discussion of Tunnel 1S results deals with defining the effects of variation of tunnel and model parameters upon the starting and unstarting pressure ratio requirements. The minimum diffuser area ratios for starting and operating were also defined by increasing or decreasing the diffuser area ratio for maximum tunnel pressure ratio at a particular Mach number until flow started or unstarted. The Tunnel 1S data are utilized to obtain an estimate of the available tunnel performance for the full-scale test in Tunnel 16S.

Because of the similarities of the data trends, data for only some of the possible combination of all tunnel and model parameters were obtained. Furthermore, only those data which are considered sufficient to satisfy the objectives of the test are presented herein.

4.2.2 Effects of Tunnel Parameters

The discussion in this section of the report pertains to the effects of variation of Mach number, diffuser area ratio, and test section wall angle upon the starting and unstarting tunnel pressure ratio requirements. For data presentation, diffuser contour number (DCN), rather than diffuser area ratio (ϕ), is utilized. The realtionship between DCN and ϕ is given in Fig. 12. Variation of the test section wall angle had no effect upon the minimum pressure ratio requirements for starting and unstarting. All data presented herein are for θ_W = 30 min.

The starting and unstarting processes of a supersonic wind tunnel with long, large blockage models are not as clearly defined as they are for smaller models. Consequently, a judgement must be made as to what static pressure distribution represents a started or an unstarted tunnel. Consideration must be given to satisfactory flow conditions as they pertain to full-scale inlet/engine testing. Typical wall static pressure distributions obtained in Tunnel 1S for the defined started and unstarted tunnel are shown in Figs. 20 and 21 for nacelle configurations I and II. Data could not be obtained with configuration II at M_∞ = 1.8. The data in Fig. 20 indicate two distinct starting patterns which are designated minimum starts and full starts. During tunnel flow start, the tunnel shock system stabilized at a location just downstream of the

trailing edge of the strut. Further increases in the pressure ratio moved the shock downstream until it finally stabilized in the diffuser, where additional increase in pressure ratio produced no change in the tunnel wall static pressure distribution. The data in Fig. 20 indicate that the static pressure distributions for the two defined starts are identical to a point well downstream of the model bypass doors and that both starts provide equally satisfactory flow conditions for inlet testing. The distinction between the two starting patterns was made during testing with nacelle configuration II, for which additional diffuser static pressure orifices were utilized. Only the minimum starts, therefore, were defined for the data obtained with nacelle configuration I. Both minimum and full starts were defined for the data obtained with nacelle configuration II.

The typical effect of diffuser position upon the pressure ratio requirements for nacelle configuration II with the flat plate wing is presented in Fig. 22. The symbol (∃) is used to designate the minimum diffuser contour number for starting and unstarting. The data presented in Fig. 22 indicate that variations of diffuser contour had no significant effect upon the pressure ratios required for flow starting and unstarting. All configurations tested exhibited a similar data trend. The data presented in Fig. 22 also indicate a significant difference in the minimum starting diffuser contour for the minimum start and the full start. Apparently, between these two diffuser positions, the tunnel shock system reached a stable position at the rear of the model. It is suspected that a similar flow condition would exist as the minimum operating Mach number is approached.

The typical effect of Mach number upon the minimum start and unstart pressure ratio requirements is illustrated in Fig. 23. The pressure ratio data are the minimum values for nacelle configuration II and the flat plate wing, as indicated by Fig. 22. The symbol (∃) is used to denote the minimum Mach number at which the tunnel could be started or run. The data presented in Fig. 23 indicate that the pressure ratio requirements decrease with decreasing Mach number and that there is a significant difference between the requirements for the two defined flow starts. All configuration tested exhibited a similar data trend.

4.2.3 Effects of Model Parameters

The discussion in this section of the report pertains to the effects of variation of model inlet airflow, nacelle configuration, wing configuration, inlet ramp position, bypass door position, and attitude upon the start and unstart pressure ratio requirements. For data presentation, the minimum pressure ratios for starting and unstarting at each Mach

number are utilized. The symbol (ʒ) is utilized to designate the minimum operating and starting Mach number.

The effects of inlet airflow variation upon the minimum pressure ratios for starting and unstarting at M_∞ = 2.0, 2.2, and 2.3 are presented in Fig. 24. The ratio of measured inlet weight flow to theoretical inlet capture weight flow is used for data presentation. The data presented in Fig. 24 indicate that there is only a slight variation of the required pressure ratios with inlet airflow. In general, as the inlet airflow ratio is reduced from the maximum to the minimum, the pressure ratios required for starting tend to increase and the pressure ratios required for unstarting tend to decrease. Because the full-scale test in Tunnel 16S will have an operating range which includes maximum and reduced airflows, the maximum pressure ratio requirements are utilized to obtain estimates of Tunnel 16S performance.

The effect of inlet airflow variation on the minimum starting and running Mach number for nacelle configuration II is presented in Fig. 25. The data presented for $W_E/W_C > 0.6$ were obtained with the model flow measuring orifice removed, and those presented for $WE/W_C < 0.2$ were obtained utilizing a 0.9-in.-diam orifice. All other data which are presented were obtained with a 1.8-in.-diam orifice installed in the model. The data presented in Fig. 25 indicate that decreases in inlet airflow significantly increase the minimum starting and operating Mach number. To obtain estimates of the available performance of Tunnel 16S for the full-scale test both maximum and reduced inlet airflows were utilized.

The effect of nacelle configuration upon the minimum pressure ratios for starting and unstarting is presented in Fig. 26. The data presented in Fig. 26 indicate that the tunnel is slightly harder to start with nacelle configuration II, but the flow unstart characteristics do not change significantly with nacelle configuration. The data also indicate that the minimum starting and operating Mach numbers are significantly higher for configuration II than for configuration I. The maximum tunnel blockage was the same for both configurations; however, the blockage distribution changed because of the nacelle and strut modifications, which were described in Section 2.2. In an attempt to isolate this effect, data were obtained with nacelle configuration II without the strut leading edge extension, and these data indicated no significant change in the minimum operating and starting Mach numbers. A flow-measuring orifice was usually utilized for data obtained with configuration II, whereas no orifice was used for data obtained with configuration I. Operation with the orifice installed is considered the preferred operating technique for Tunnel 1S.

When no orifice plate was utilized, testing at reduced inlet airflows was precluded because inlet instabilities which occurred would unstart the tunnel. Utilization of the measuring orifice reduced the inlet airflow by a factor of about two. According to the data presented in Fig. 25, such a reduction in inlet airflow would increase the minimum starting and operating Mach numbers by 0.08 and 0.04, respectively. Only a part of the difference in performance with nacelle configurations I and II, which is indicated in Fig. 26, can be attributed to the use of the measuring orifice. The principal reason for the difference in performance with configurations I and II is attributed to configuration II external nacelle modifications which increased the tunnel blockage ahead of the maximum blockage station.

The effect of wing configuration variation upon the minimum pressure ratios for starting and unstarting is presented in Fig. 27. The data in Fig. 27 indicate that the full contoured wing required the highest pressure ratio for starting and unstarting throughout the Mach number range. The lowest unstart pressure ratios were obtained with the flat plate wing configuration; however, the pressure ratio required for starting the flat plate wing was slightly higher than for the basic contoured wing. Preliminary design of the full-scale test hardware indicates that the flat plate wing should be utilized to obtain estimates of the available performance of Tunnel 16S.

The effects of inlet ramp position on the minimum pressure ratio for starting and unstarting are presented in Fig. 28. The data presented in Fig. 28 indicate that there was no significant difference in the tunnel performance with the $M_\infty = 2.2$ cruise and $M_\infty = 2.2$ restart ramp positions. With the $M_\infty = 1.8$ cruise ramp position, slightly higher pressure ratios were required to obtain a full start. Because it is representative of the B-1 aircraft design point, the $M_\infty = 2.2$ cruise ramp was utilized to obtain estimates of the performance available for the full-scale test in Tunnel 16S.

The effects of bypass door position on minimum pressure ratio for starting and unstarting are shown in Fig. 29. The data in Fig. 29 indicate that bypass door position had no effect upon the minimum starting pressure ratio requirements. Although opening the bypass door from 0 to 15 deg produced an increase in the minimum flow unstart pressure ratios, further opening the door to 30 deg produced no additional increase in the minimum pressure ratio requirements. Because a 30-deg bypass position is a representative bypass position for tunnel starting, it was utilized for estimates of Tunnel 16S performance for the full-scale test.

The effect of model attitude on the minimum pressure ratios for starting and unstarting is presented in Fig. 30. The data in Fig. 30 indicate that increasing angle of attack from 0 to 3 deg does not significantly affect the minimum starting and unstarting pressure ratio requirements. Because a fixed model attitude would simplify the full-scale design, nacelle configuration II was tested at a fixed attitude of 2.67 deg, which was considered representative of the B-1 aircraft cruise attitude.

4.2.4 Summary of Tunnel 1S Results

The evaluation of the effects of the various tunnel and model variables upon tunnel starting and operating performance has been presented in the preceding sections of this discussion. In this summary an estimation of the minimum Mach number and the starting and operating pressure ratios and diffuser area ratios available for the full-scale tests in Tunnel 16S is presented. The Tunnel 16S performance estimate is based on the Tunnel 1S data obtained at θ_W = 30 min with the flat plate wing, α = 2.67 deg, 2.2 cruise ramp, bypass position = 30 deg, nacelle configuration II, and with both maximum and reduced inlet airflows.

The minimum diffuser area ratios for starting and operating in Tunnel 1S are presented in Fig. 31. The diffuser area ratios required in Tunnel 1S generally agree very well with those required in Tunnel 16S. Because the data presented in Fig. 31 are the absolute lower limits, an area ratio increment of about 0.04 should be added to the data presented to provide a satisfactory margin for starting and operating in Tunnel 16S.

The minimum Mach numbers for starting and operating vary significantly with inlet airflow. The variation of the minimum Mach numbers for starting and operating is shown in Fig. 32. Because the engine will be windmilling both before and after the tunnel is started, an estimation of the windmill airflow ratios for the full-scale test is also presented in Fig. 32. The data in Fig. 32 indicate that the minimum Mach number at which the tunnel can be started for the full-scale B-1 test is about 1.96. The minimum Mach number at which the tunnel can be operated for the full-scale B-1 test varies from about 1.83 for full inlet airflow to about 1.88 at engine windmill airflow. It should be pointed out that, as indicated by Fig. 26, nacelle configuration I provided a wider tunnel operating range. Presently, however, nacelle configuration II has been selected for the full-scale test.

A summary of the pressure ratio requirements for starting and operating Tunnel 16S for the full-scale test is presented in Fig. 33. The pressure ratios available in Tunnel 16S, which are discussed in Appen-

dix III, are also shown in Fig. 33. The required starting pressure ratios which are presented are those that would be required for tunnel starts at engine windmill airflow. The required operating pressure ratios which are presented are based on the unstart pressure ratios with full inlet airflow and include a pressure ratio margin to preclude tunnel unstarts during testing. The increment of pressure ratio between Tunnels 16S and 1S, as presented in Appendix III, was also utilized in estimating the starting and operating pressure ratio requirements for Tunnel 16S.

The data presented in Fig. 33 indicate that the starting and operating pressure ratio requirements for the full-scale B-1 test are within the Tunnel 16S capability. Mach number 2.3, however, must be started and operated in a C234 compressor configuration.

SECTION V
CONCLUSIONS

Based on the results of a blockage test using a 1/16-scale model of the B-1 aircraft inlet, the following conclusions are made:

1. The maximum Mach number estimated to be available for the full-scale B-1 test in Tunnel 16T is 1.0. To be able to obtain a full range of engine operating points considering the current design of the full-scale test nacelle, testing in Tunnel 16T may be restricted to $M \leq 0.90$.
2. The estimated starting and operating pressure ratio requirements for the full-scale B-1 test are within the Tunnel 16S capability.
3. The minimum starting and operating Mach numbers estimated to be available for the full-scale B-1 test in Tunnel 16S are 1.96 and 1.83, respectively. The minimum operating Mach number at windmill airflow is estimated to be 1.88.
4. The minimum starting and operating Mach number obtained in Tunnel 1S with nacelle configuration II was significantly higher than that for nacelle configuration I; however, nacelle configuration II has been selected for the full-scale B-1 test because of structural considerations.
5. The basic contoured wing provided the best tunnel performance in both Tunnels 1T and 1S. The tunnel performance with the flat plate wing, which has been selected for the full-scale B-1 test, is not significantly different.

6. The auxiliary weight flow requirements in Tunnel 1T significantly decrease with increasing test section wall divergence; hence, θ_W = 60 min should be utilized for the full-scale test in Tunnel 16T.

7. The auxiliary flow requirements in Tunnel 1T vary significantly with tunnel pressure ratio. The operating pressure ratios in Tunnel 16T, however, are determined by an optimum tradeoff between auxiliary suction and tunnel pressure ratio.

8. Reducing the inlet airflow significantly affects the available performance in both Tunnels 16T and 16S. An estimate of the full-scale engine windmill airflow is utilized to obtain the estimates of tunnel performance presented herein.

9. Model attitude and probably diffuser flap opening will not significantly affect the available performance in Tunnel 16T.

10. Model attitude, model ramp and bypass positions, test section wall angle, and tunnel diffuser area ratio will not significantly affect the available performance in Tunnel 16S.

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APPENDIXES

I. ILLUSTRATIONS
II. TABLES
III. AVAILABLE PERFORMANCE IN TUNNELS 16T AND 16S

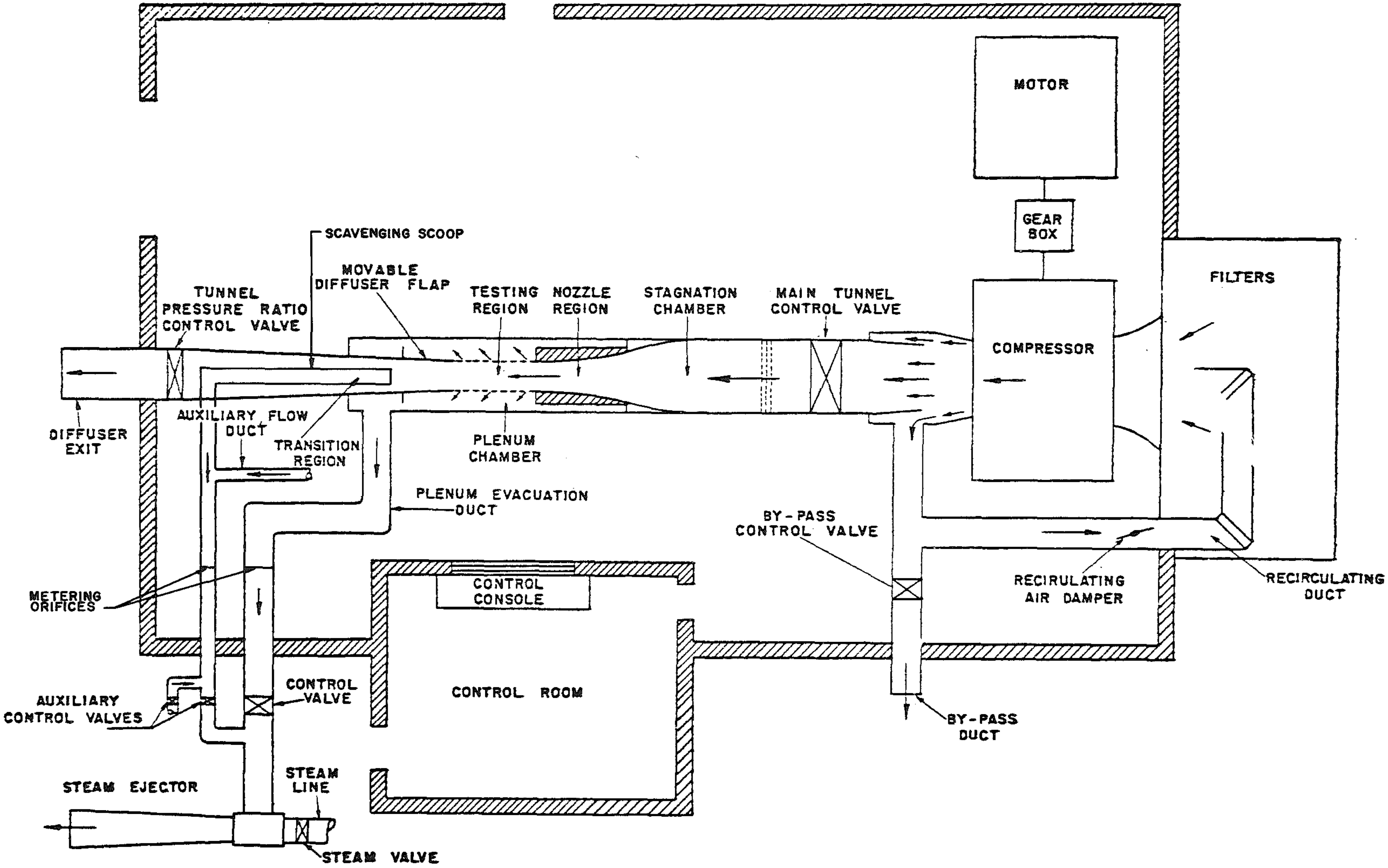


Fig. 1 General Arrangement of Tunnel 1T and Supporting Equipment

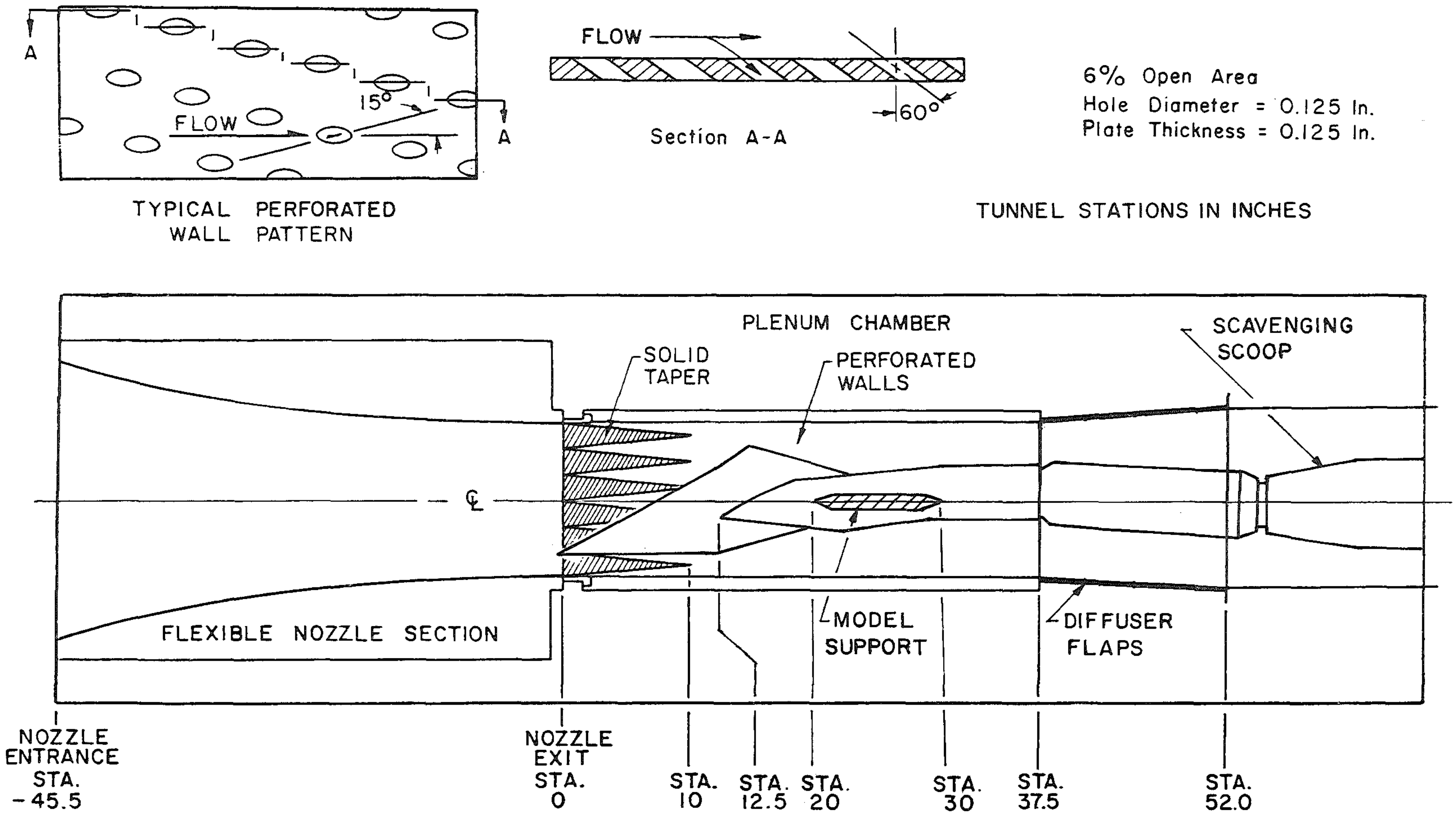


Fig. 2 Schematic of Tunnel 1T Test Leg

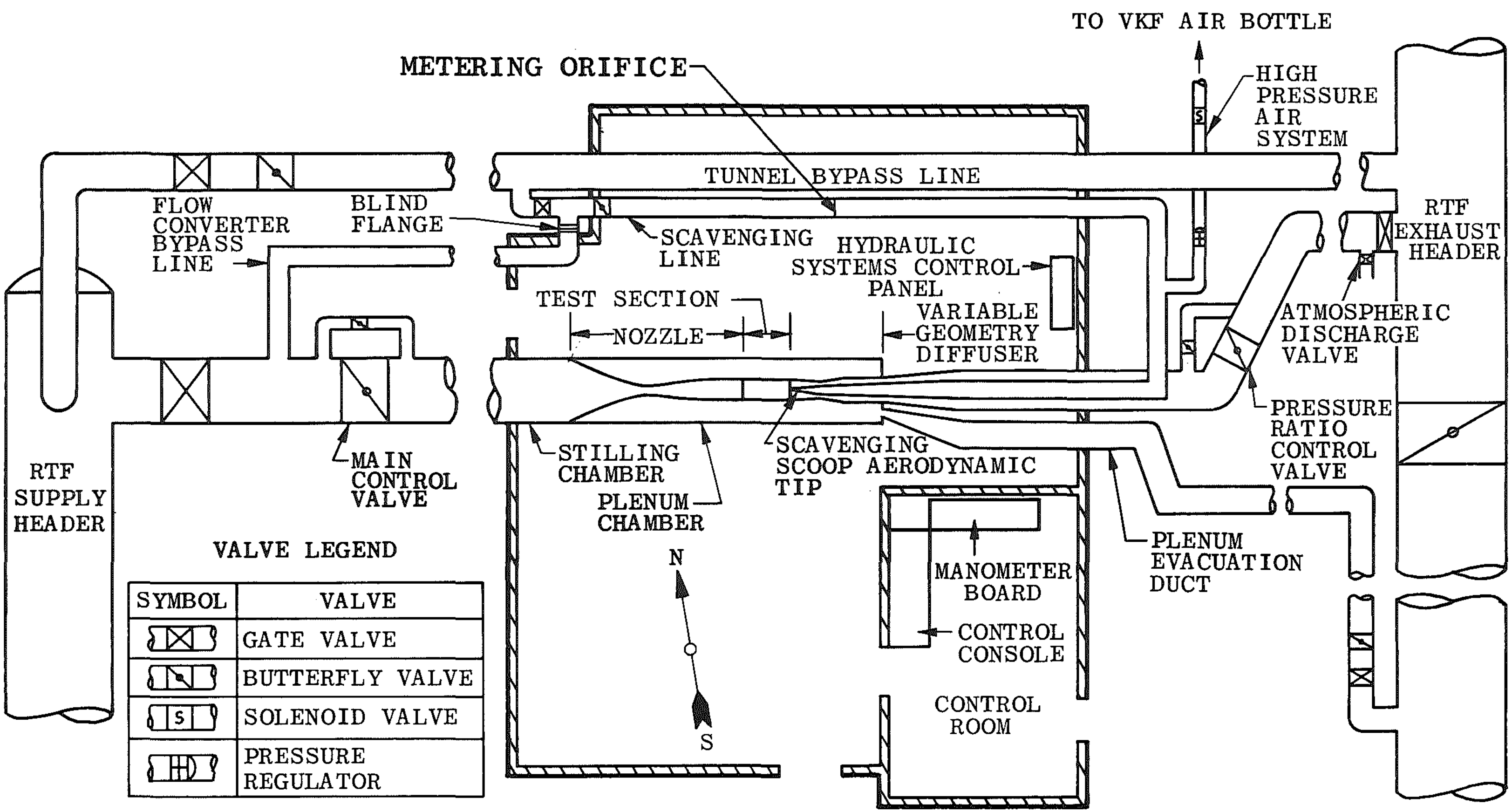


Fig. 3 General Arrangement of Tunnel 1S and Supporting Equipment

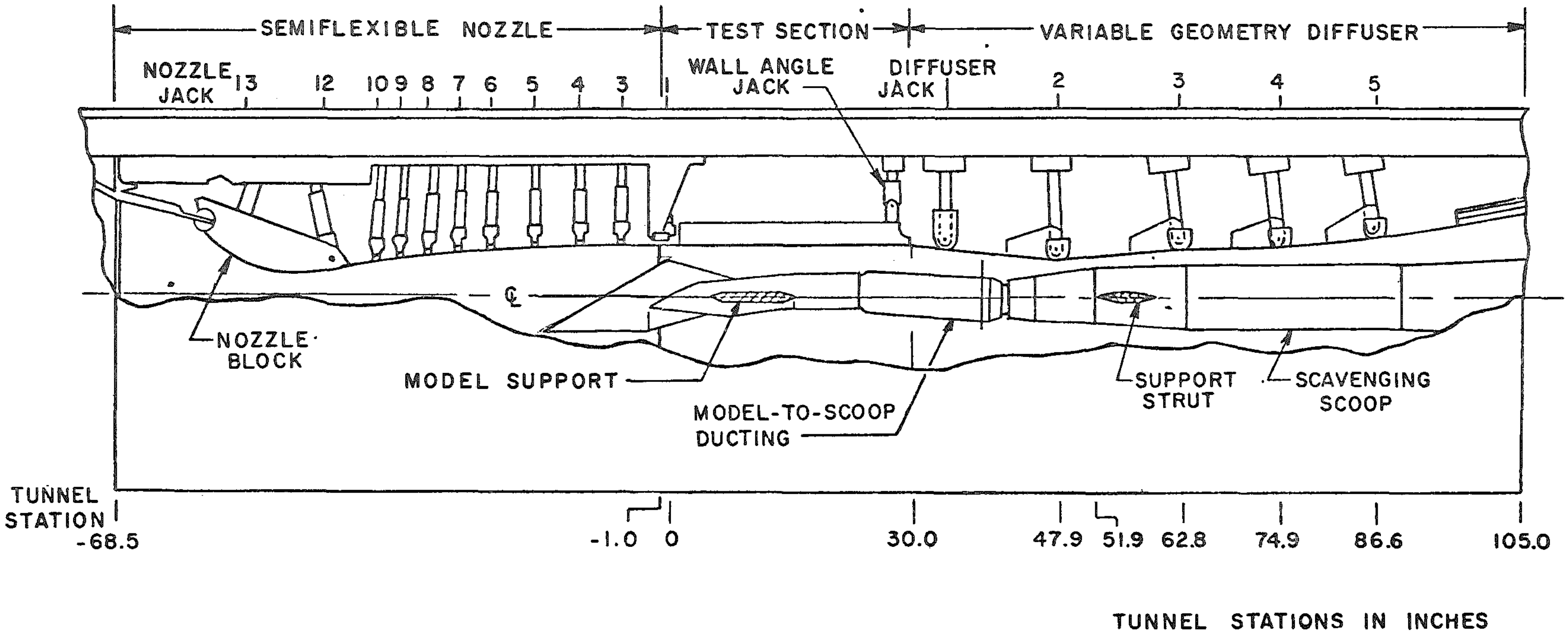


Fig. 4 Schematic of Tunnel 1S Test Leg

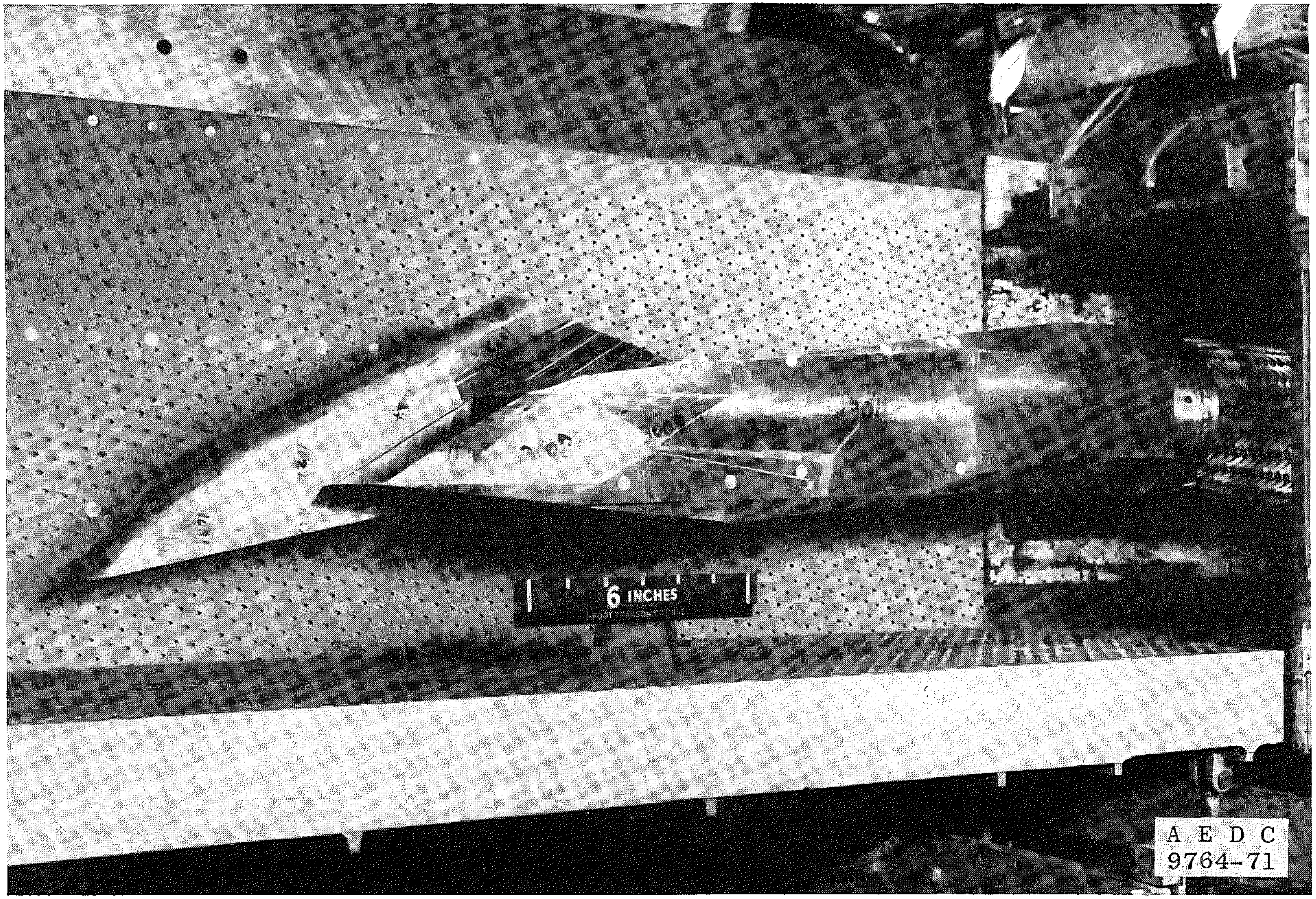


Fig. 5 Typical Model Installation in Tunnel 1T

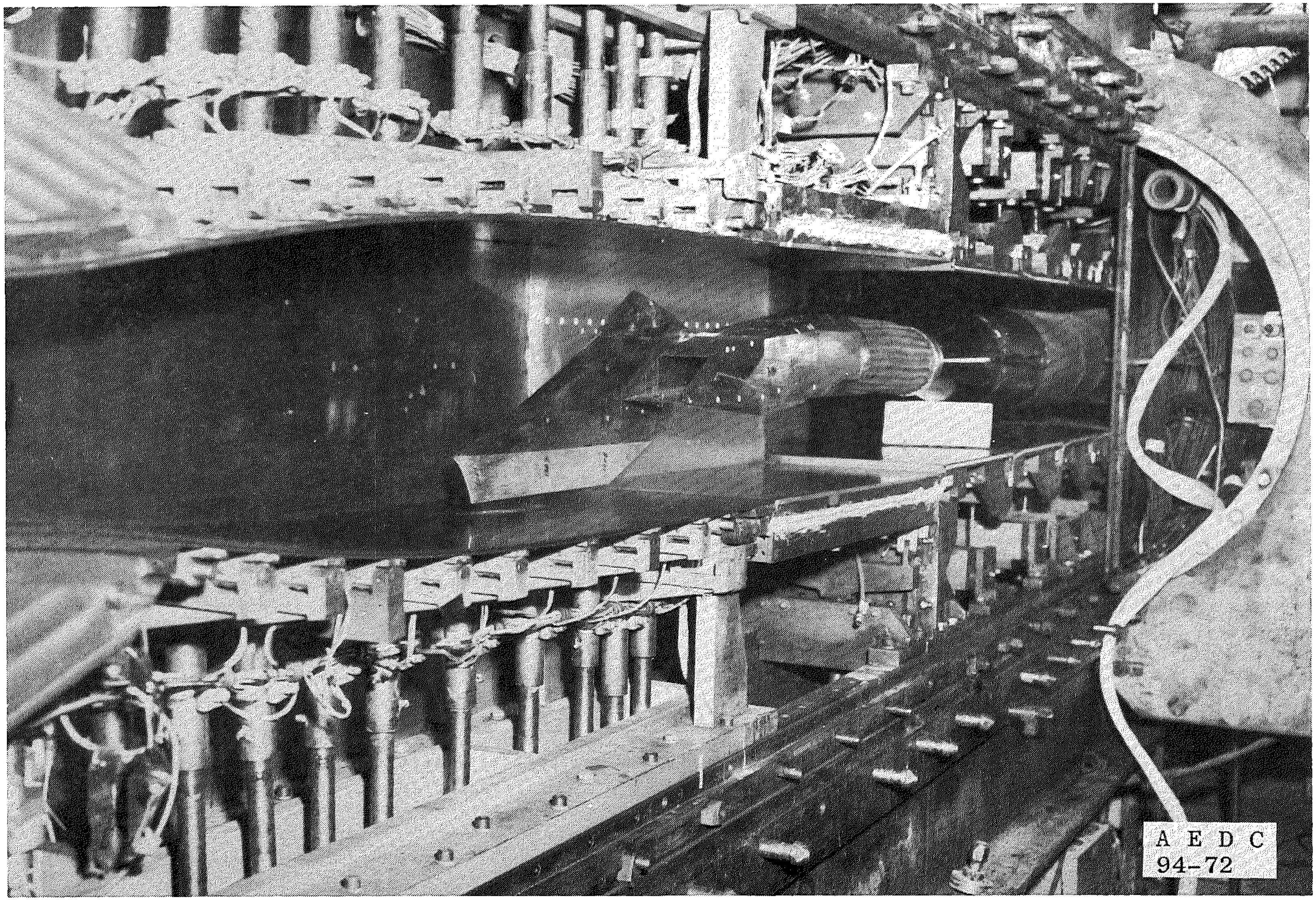
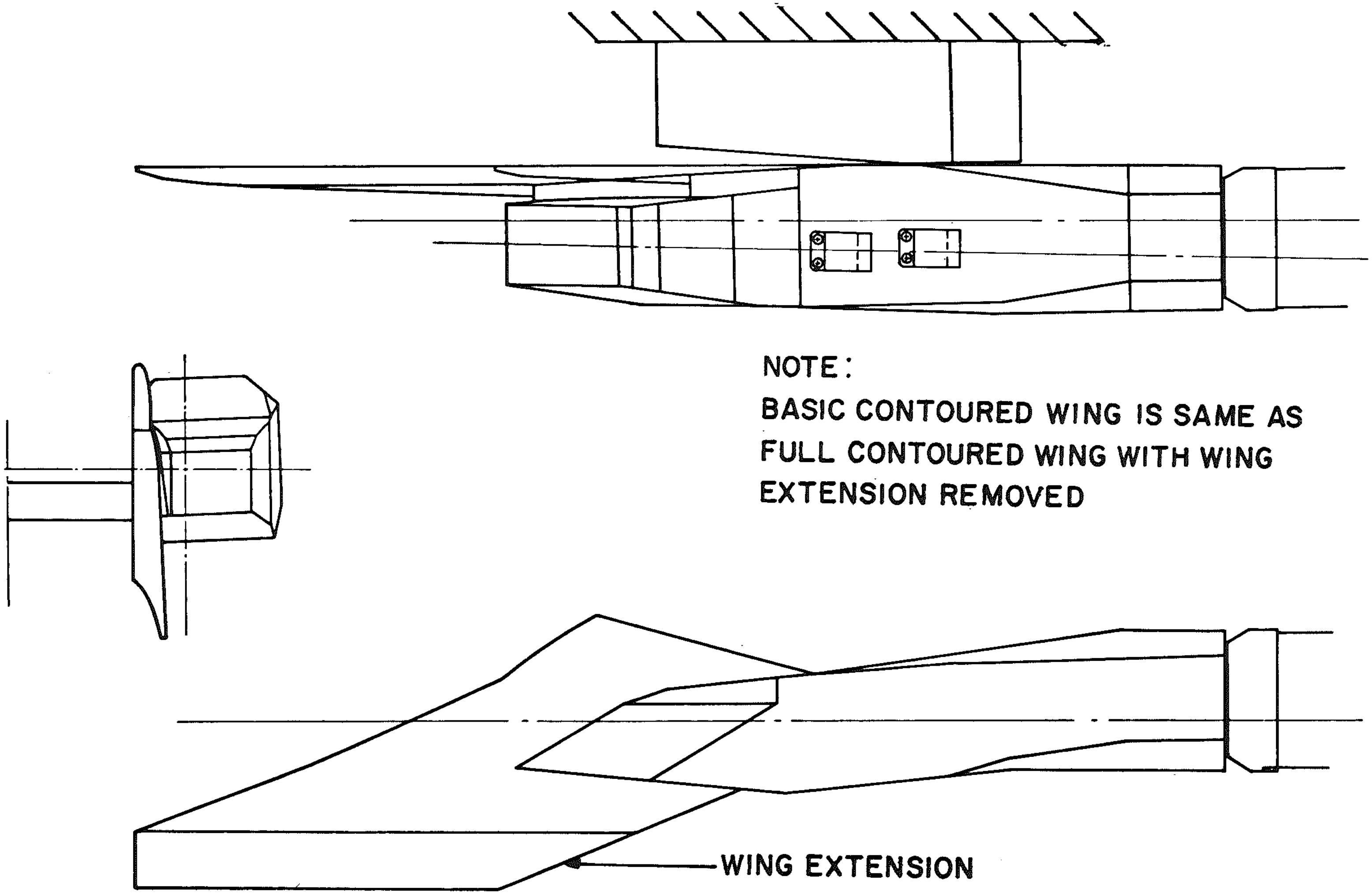
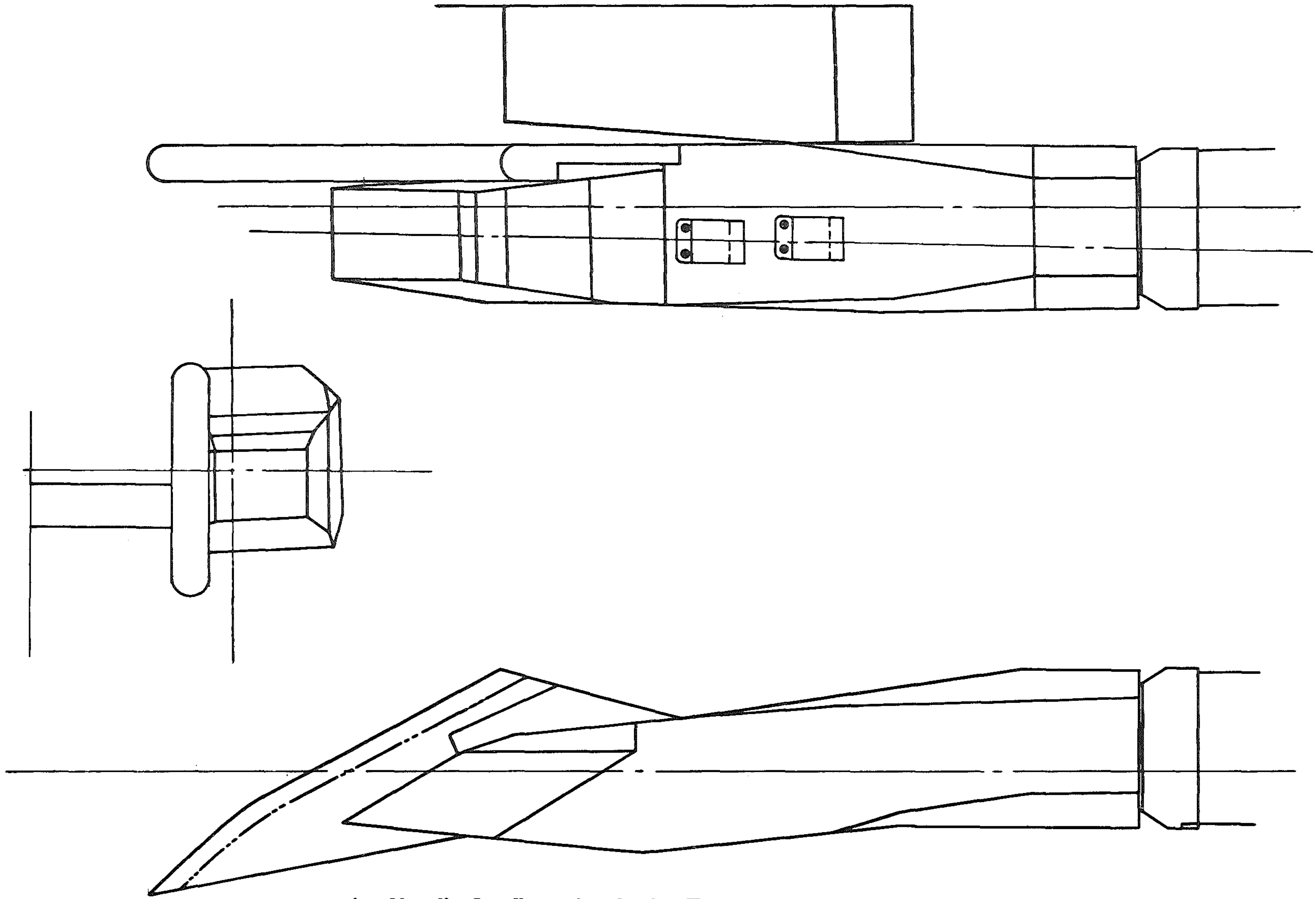


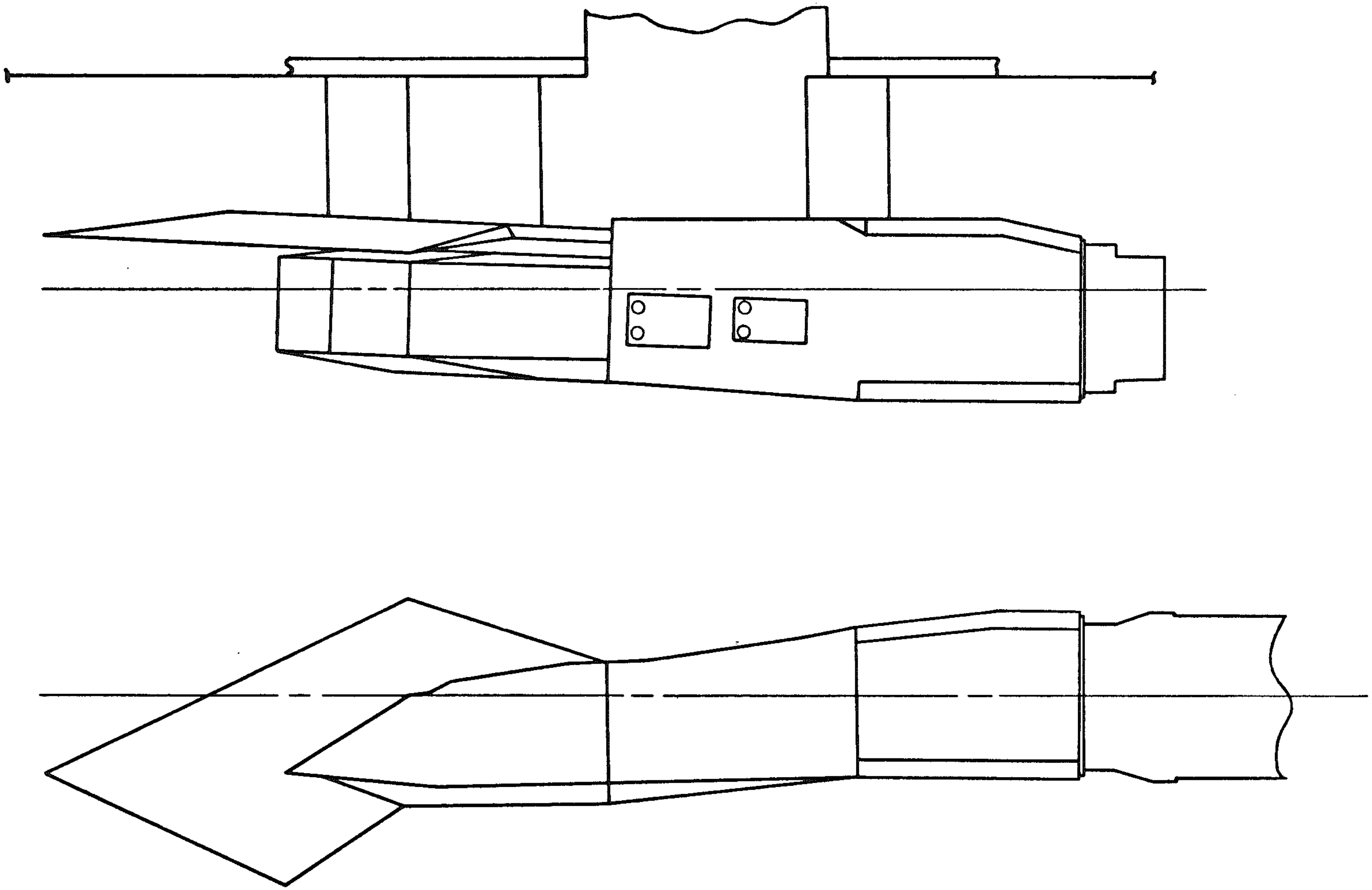
Fig. 6 Typical Model Installation in Tunnel 1S



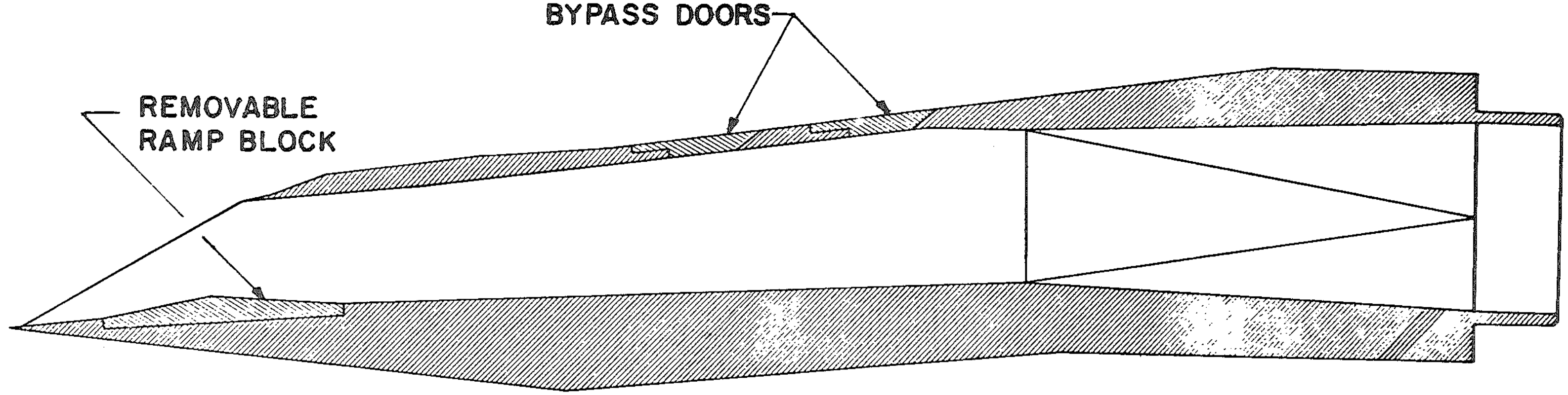
a. Nacelle Configuration I with Full Contoured Wing
Fig. 7 Model Details



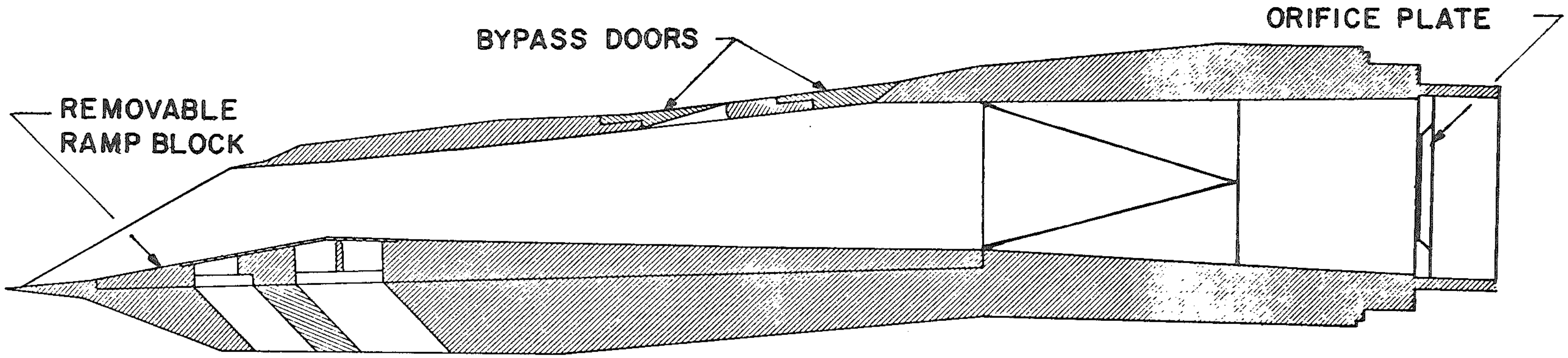
b. Nacelle Configuration I with Tunnel 1T Flat Plate Wing
Fig. 7 Continued



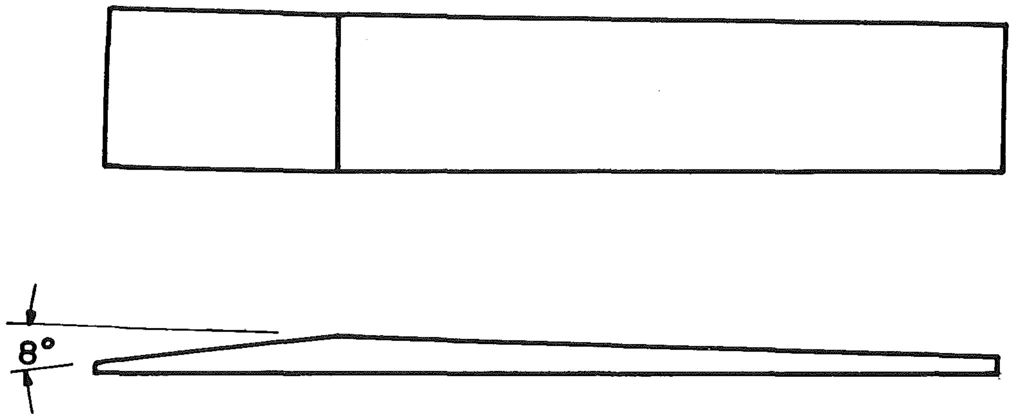
c. Nacelle Configuration II with Tunnel 1S Flat Plate Wing
Fig. 7 Concluded



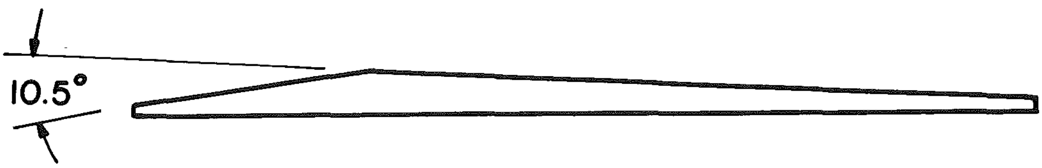
a. Nacelle Configuration I



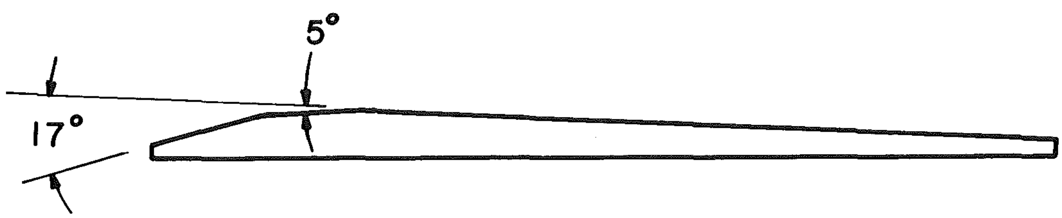
b. Nacelle Configuration II
Fig. 8 Nacelle Internal Details



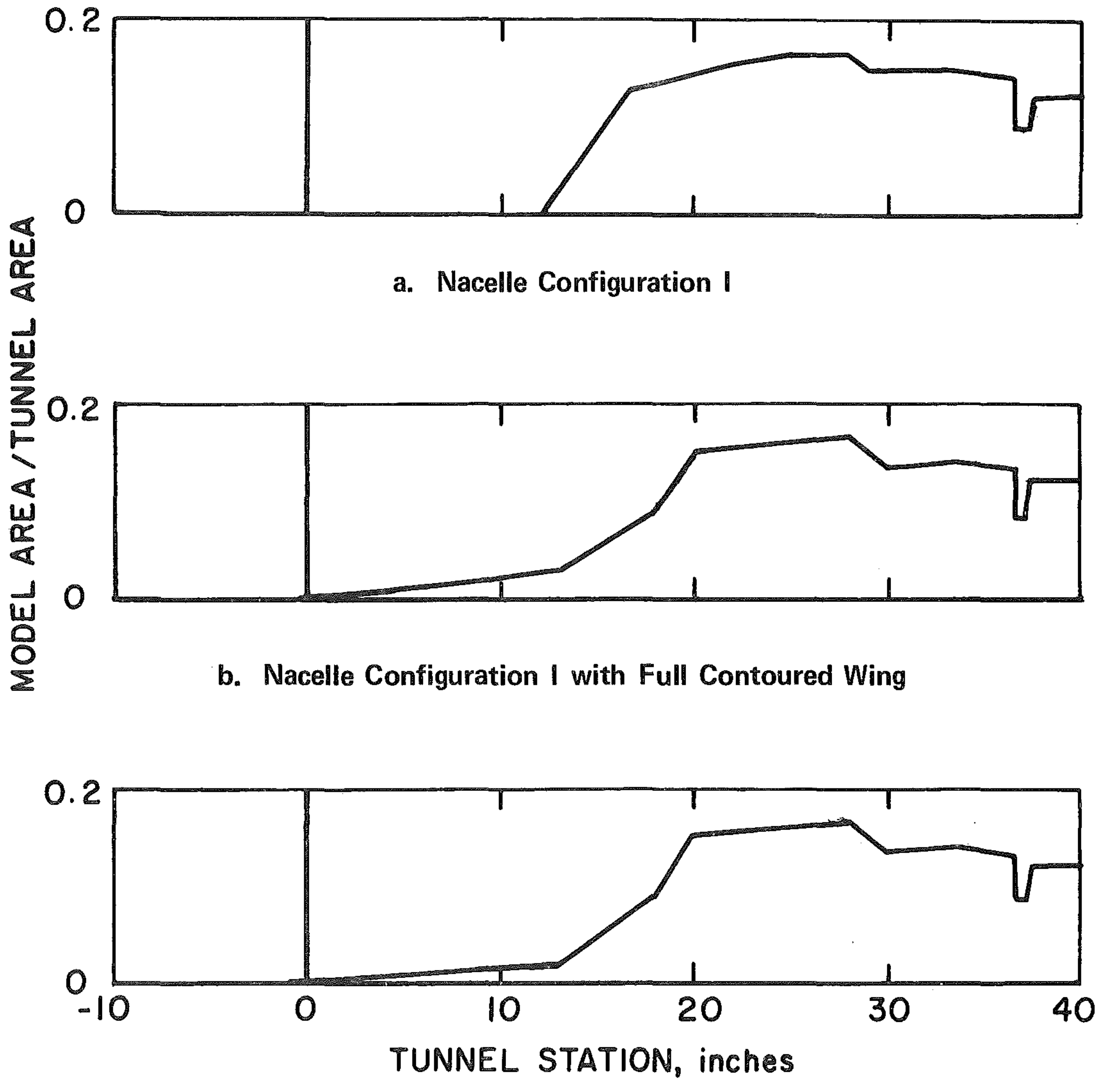
a. M_∞ = 1.8 Cruise Ramp



b. M_∞ = 2.2 Cruise Ramp



c. M_∞ = 2.2 Restart Ramp
Fig. 9 Nacelle Configuration II Ramp Blocks

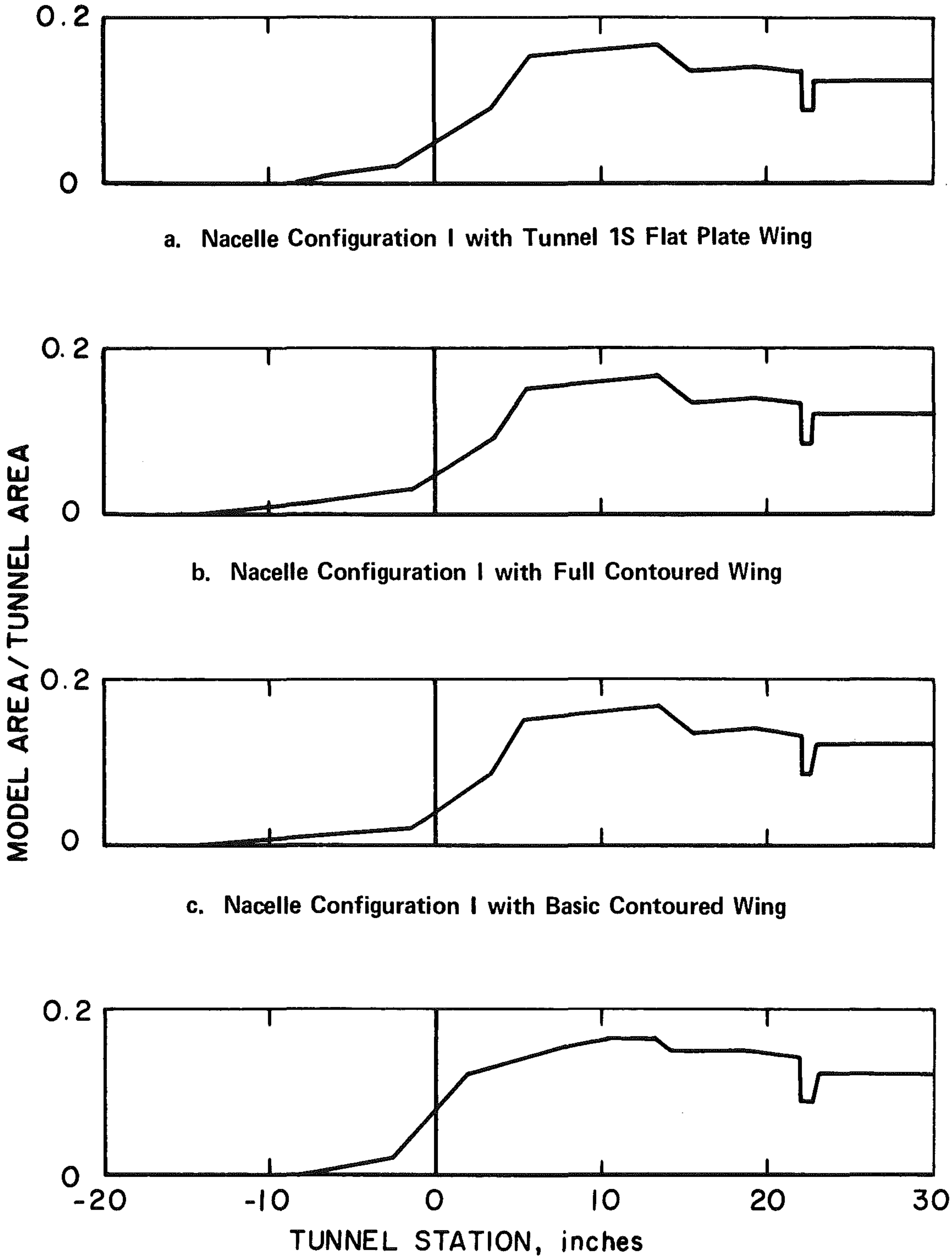


a. Nacelle Configuration I

b. Nacelle Configuration I with Full Contoured Wing

c. Nacelle Configuration I with Basic Contoured Wing

Fig. 10 Tunnel 1T Model Blockage Distributions



a. Nacelle Configuration I with Tunnel 1S Flat Plate Wing

b. Nacelle Configuration I with Full Contoured Wing

c. Nacelle Configuration I with Basic Contoured Wing

d. Nacelle Configuration II with Tunnel 1S Flat Plate Wing

Fig. 11 Tunnel 1S Model Blockage Distributions

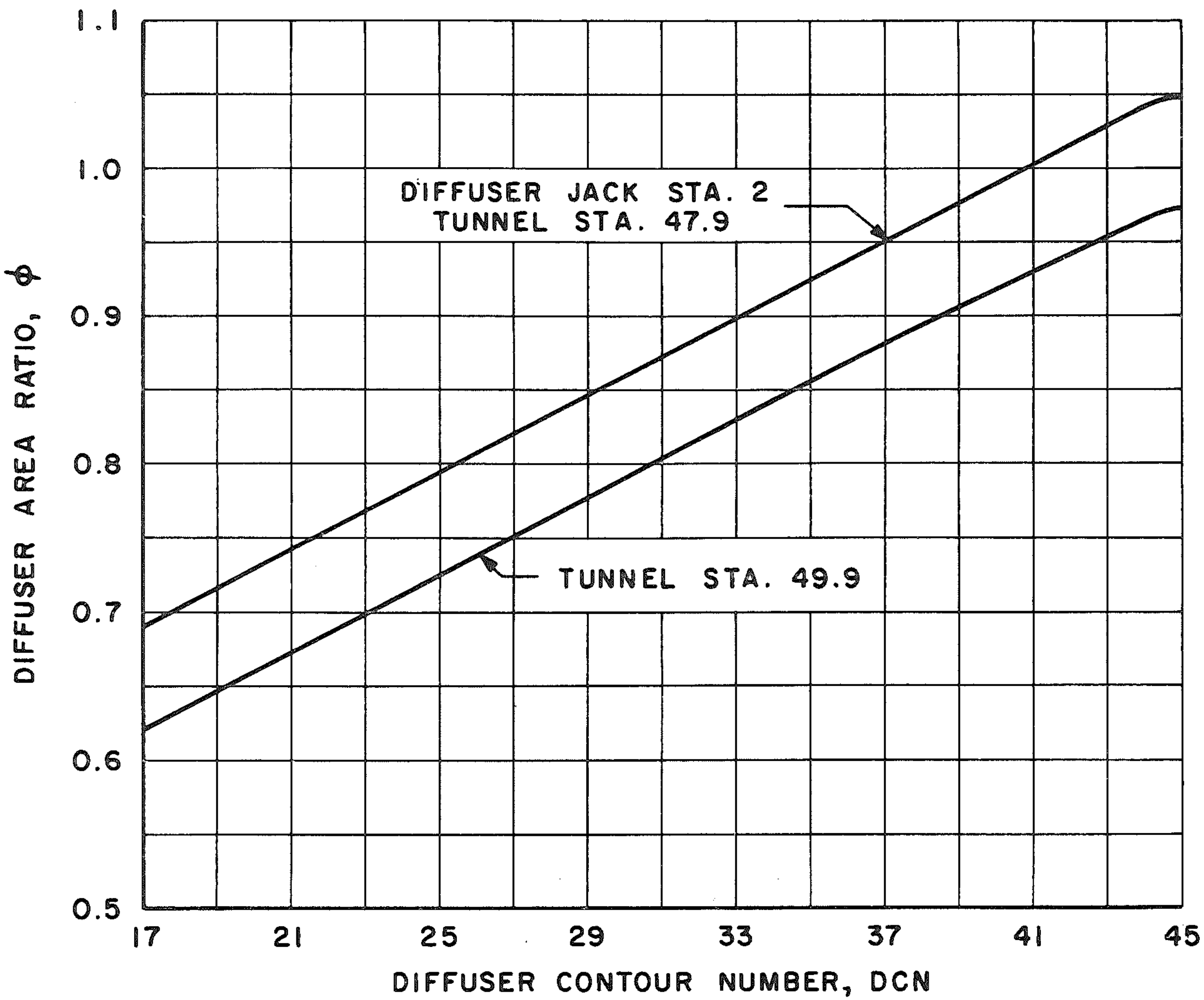
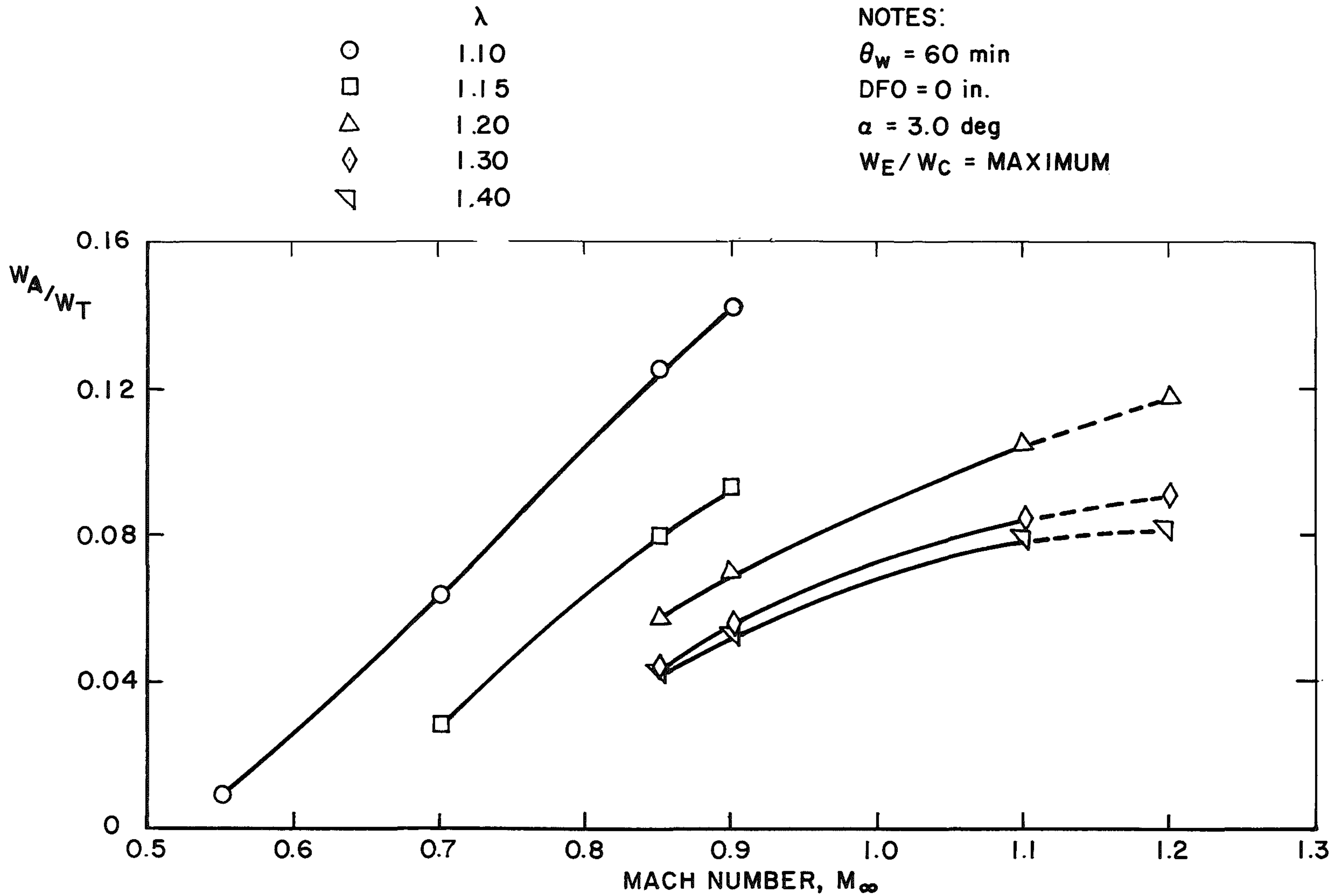
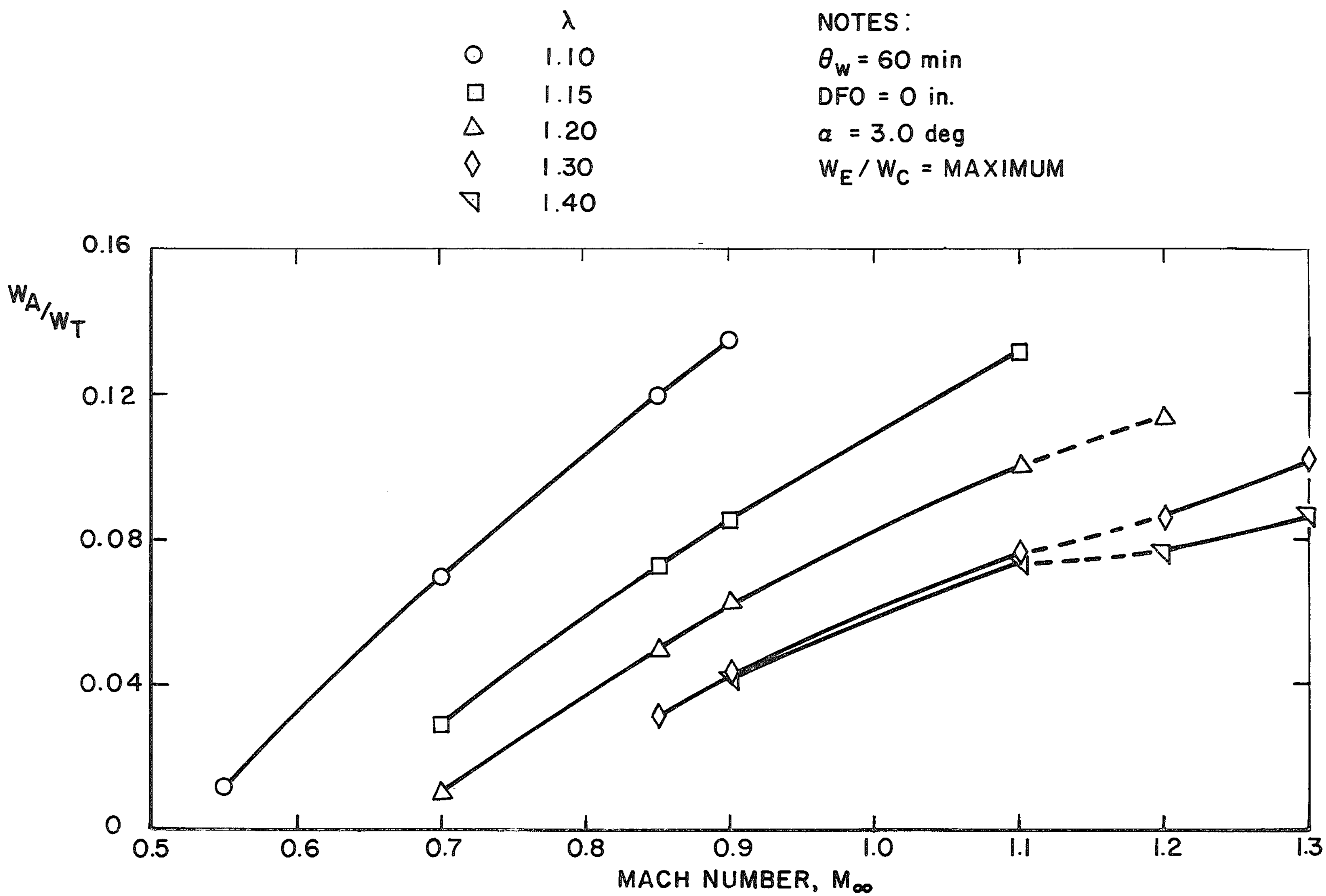


Fig. 12 Variation of Diffuser Area Ratio with Diffuser Contour Number



a. Flat Plate Wing

Fig. 13 Typical Variation of Auxiliary Weight Flow Requirements with Mach Number for Various Tunnel Pressure Ratios



b. Basic Contoured Wing
Fig. 13 Concluded

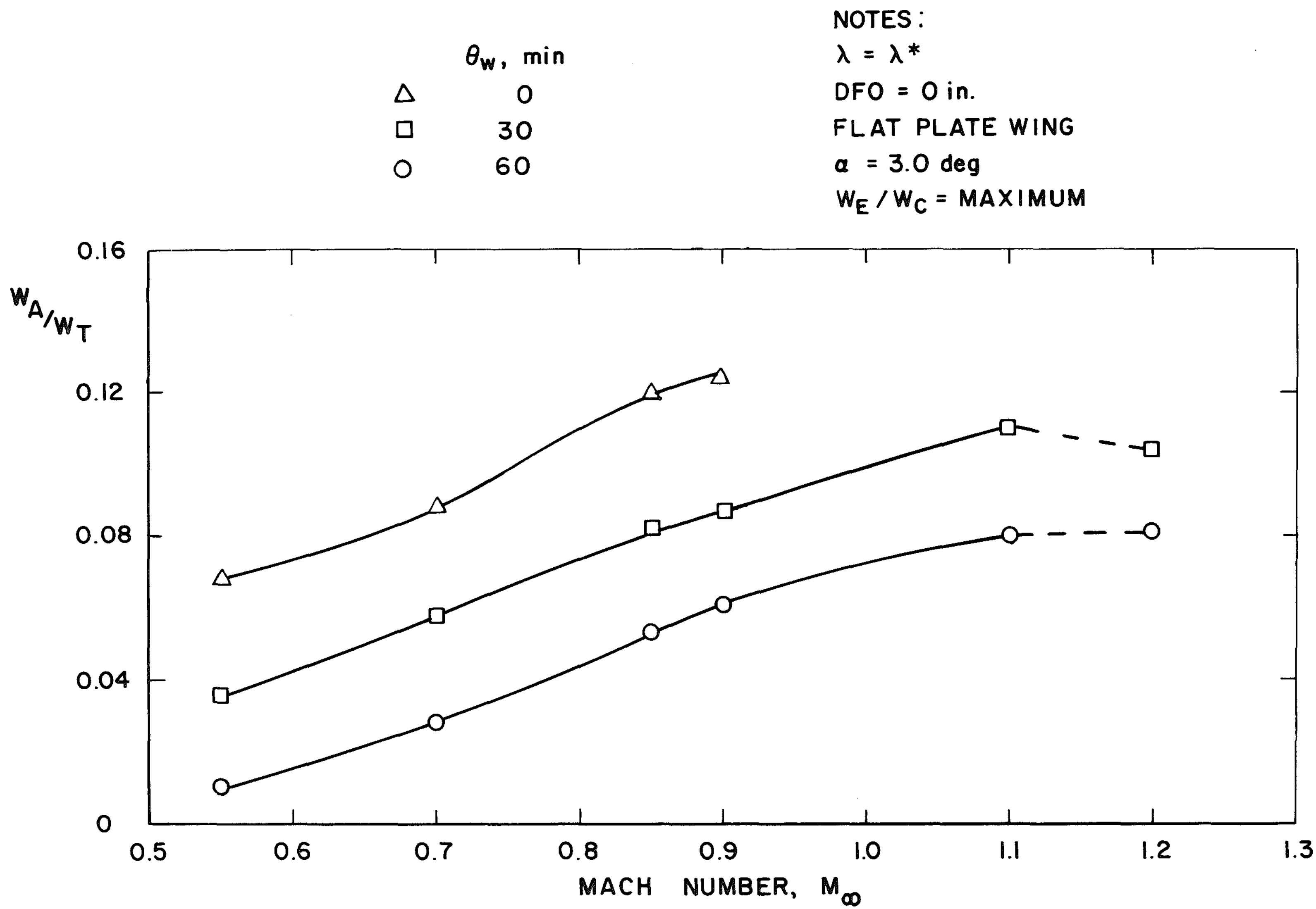


Fig. 14 Effect of Test Section Wall Angle on Auxiliary Weight Flow Requirements

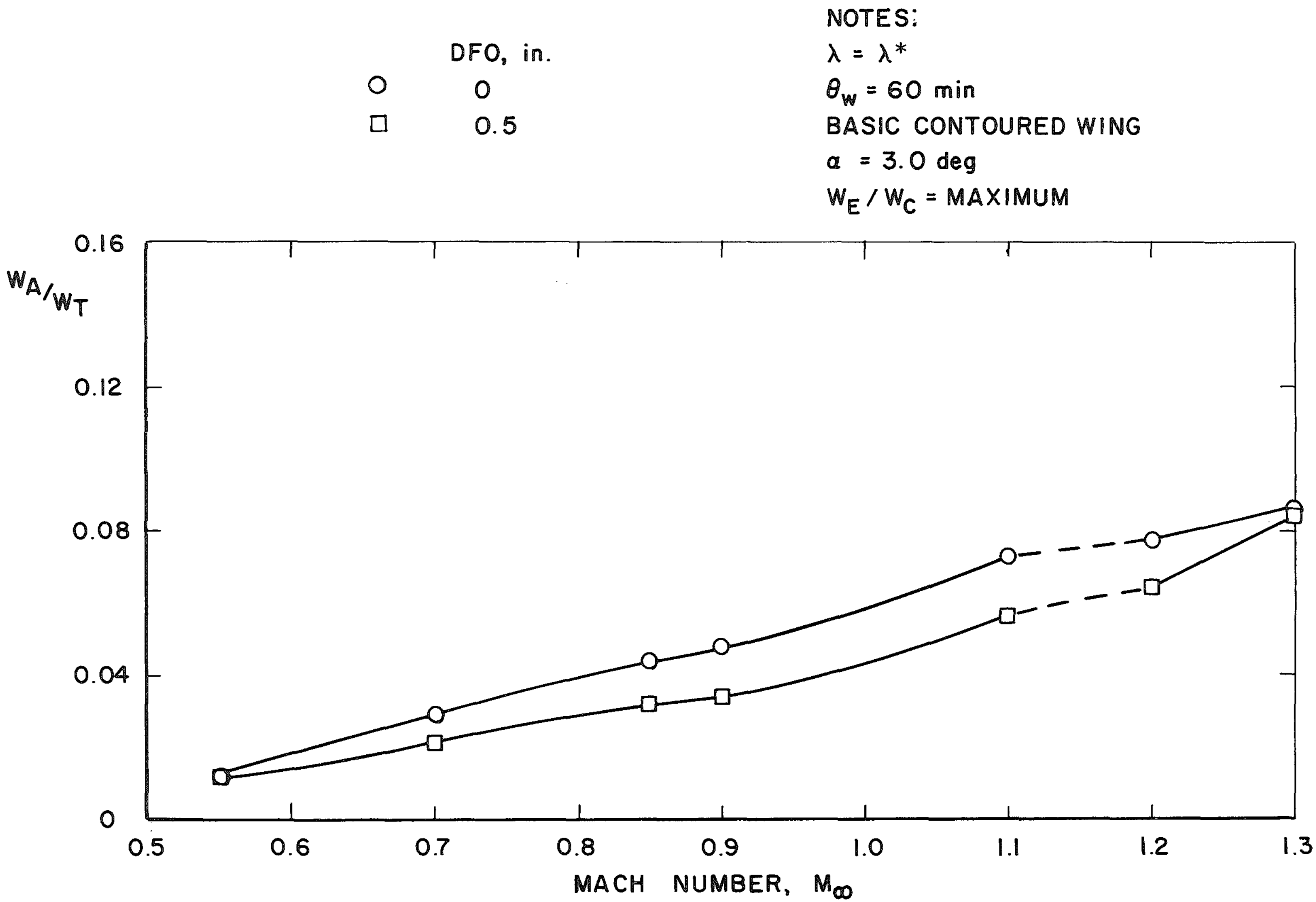


Fig. 15 Effect of Diffuser Flap Position on Auxiliary Weight Flow Requirements

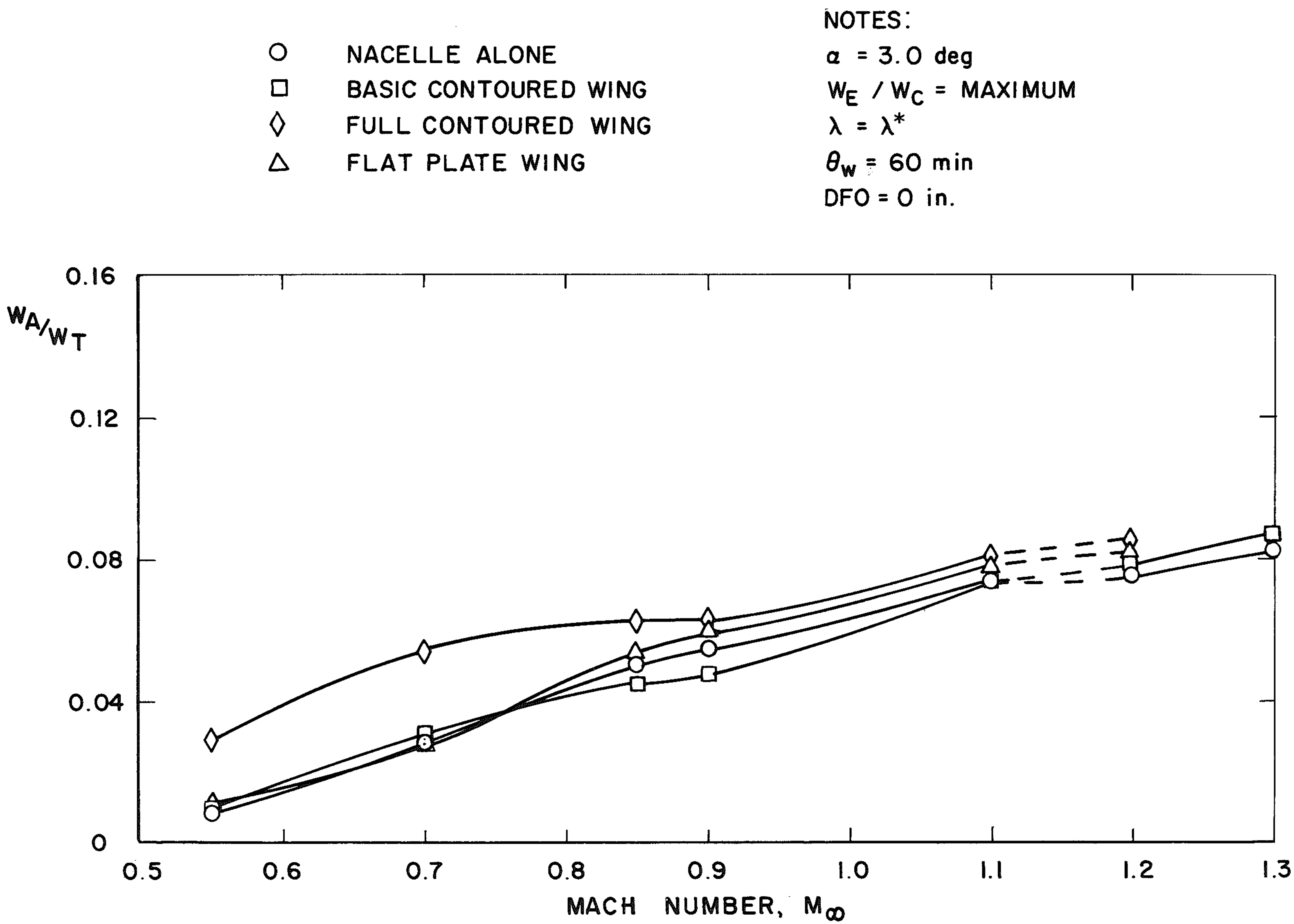


Fig. 16 Effect of Wing Configuration on Auxiliary Weight Flow Requirements

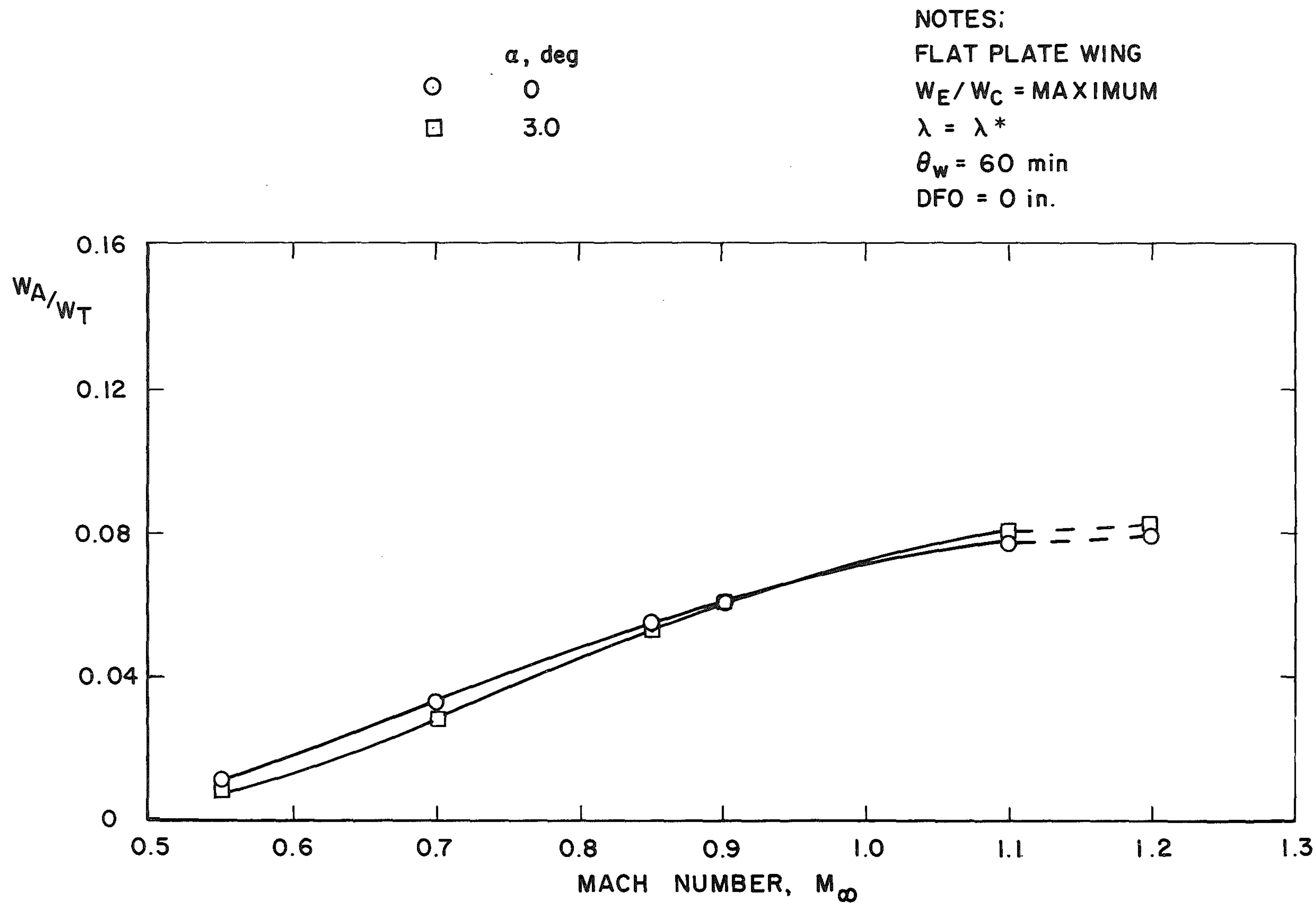


Fig. 17 Effect of Angle of Attack on Auxiliary Weight Flow Requirements

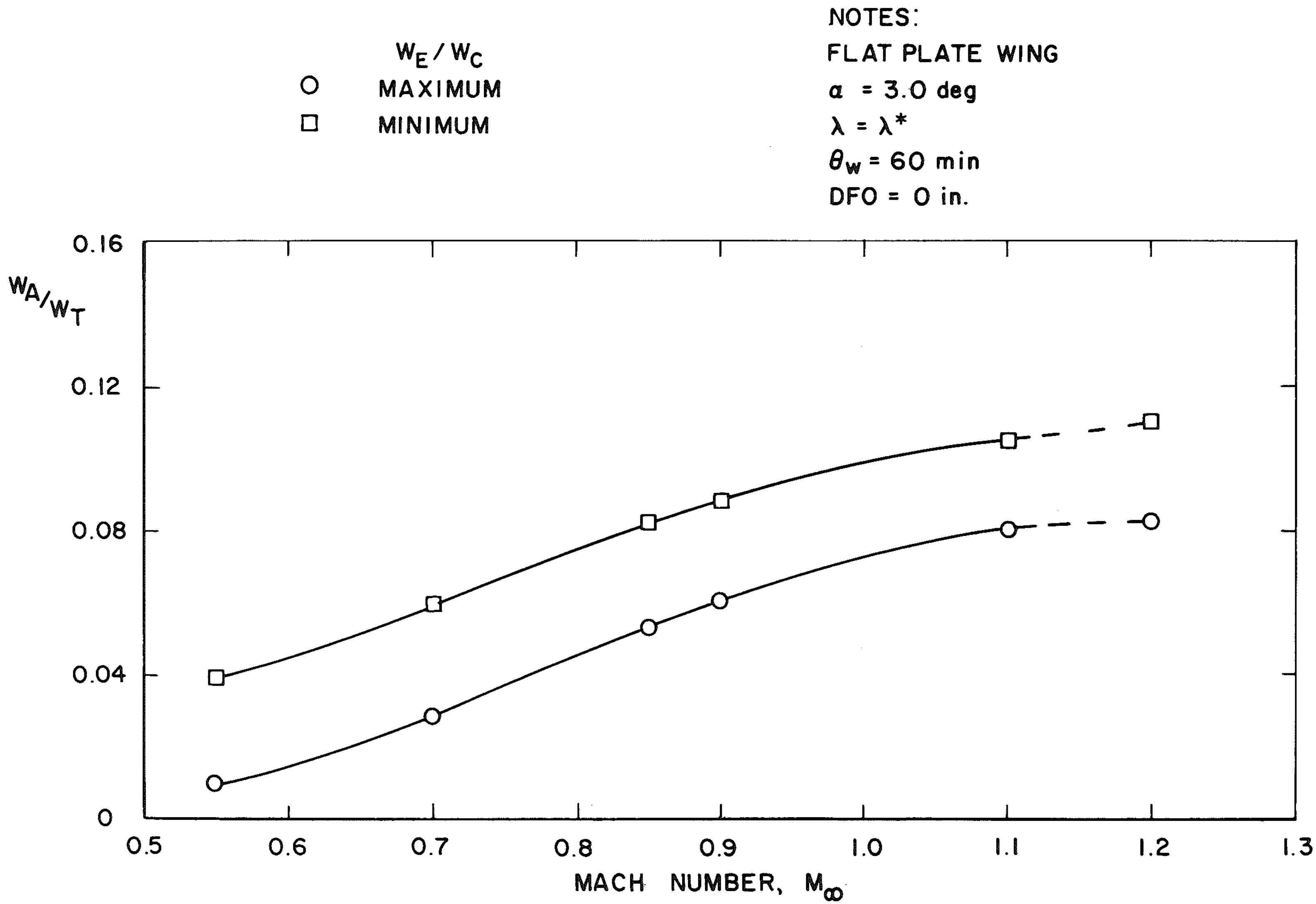


Fig. 18 Effect of Inlet Airflow on Auxiliary Weight Flow Requirements

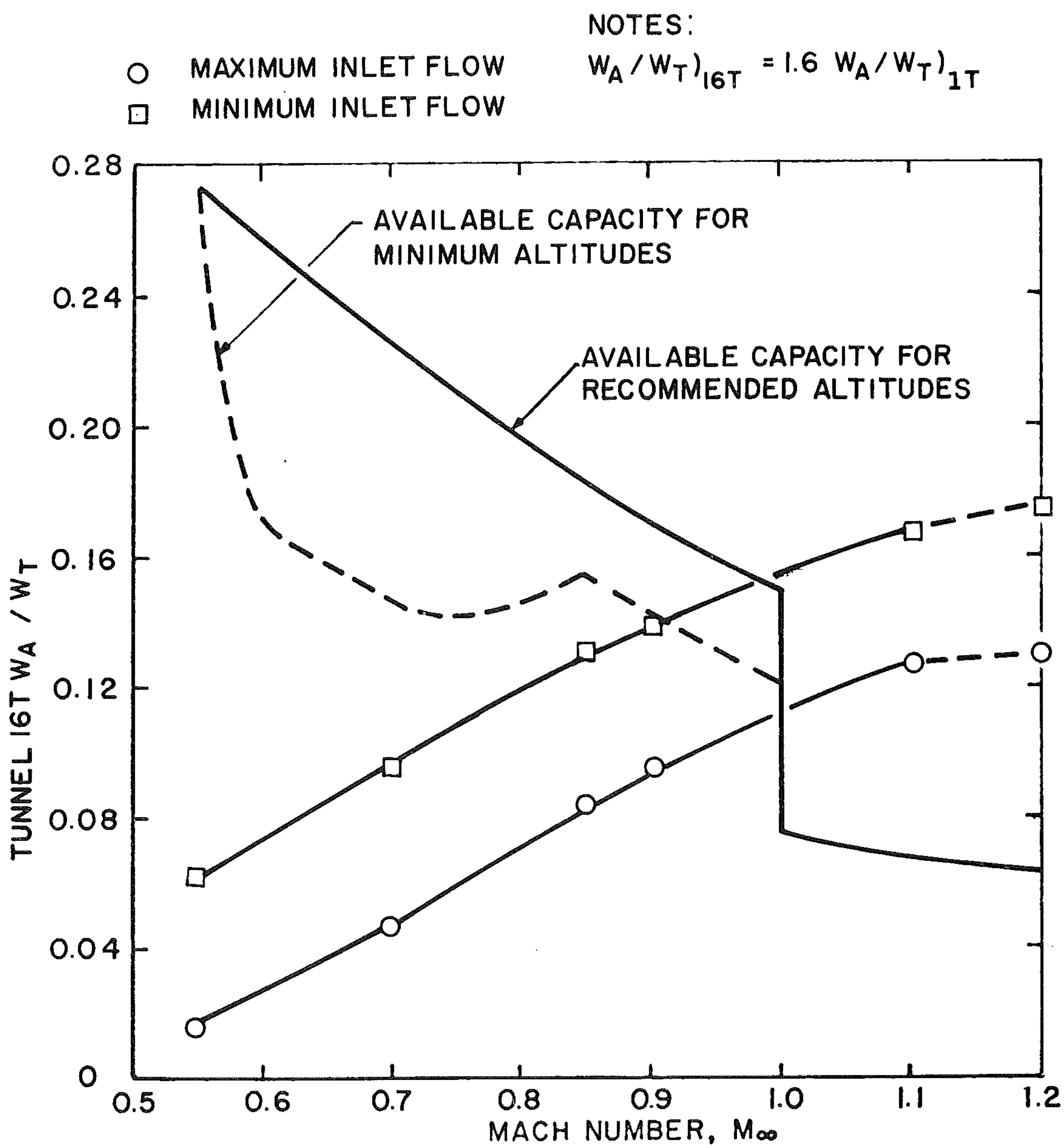


Fig. 19 Estimated Operating Range for the Full-Scale Test in Tunnel 16T

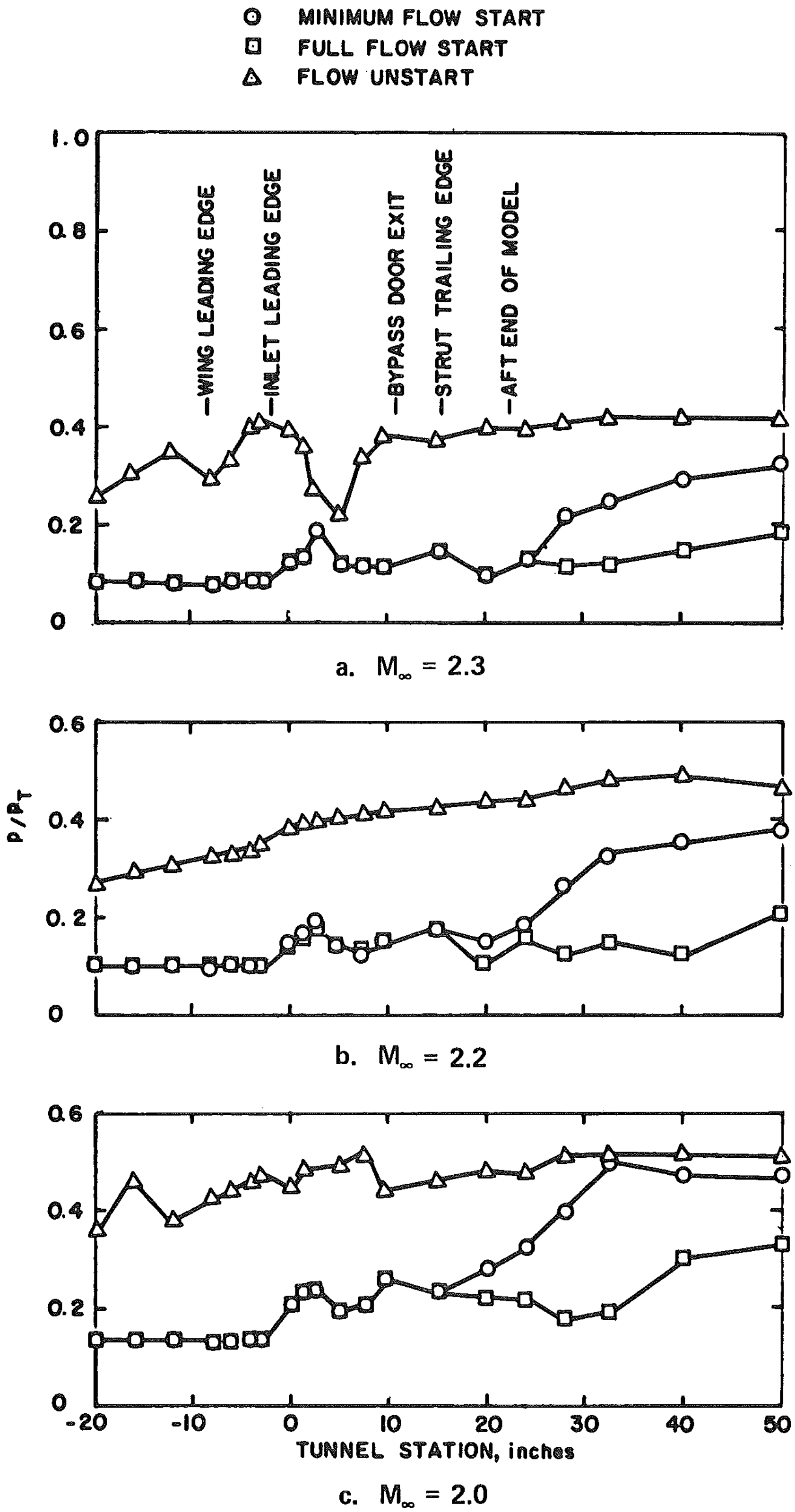
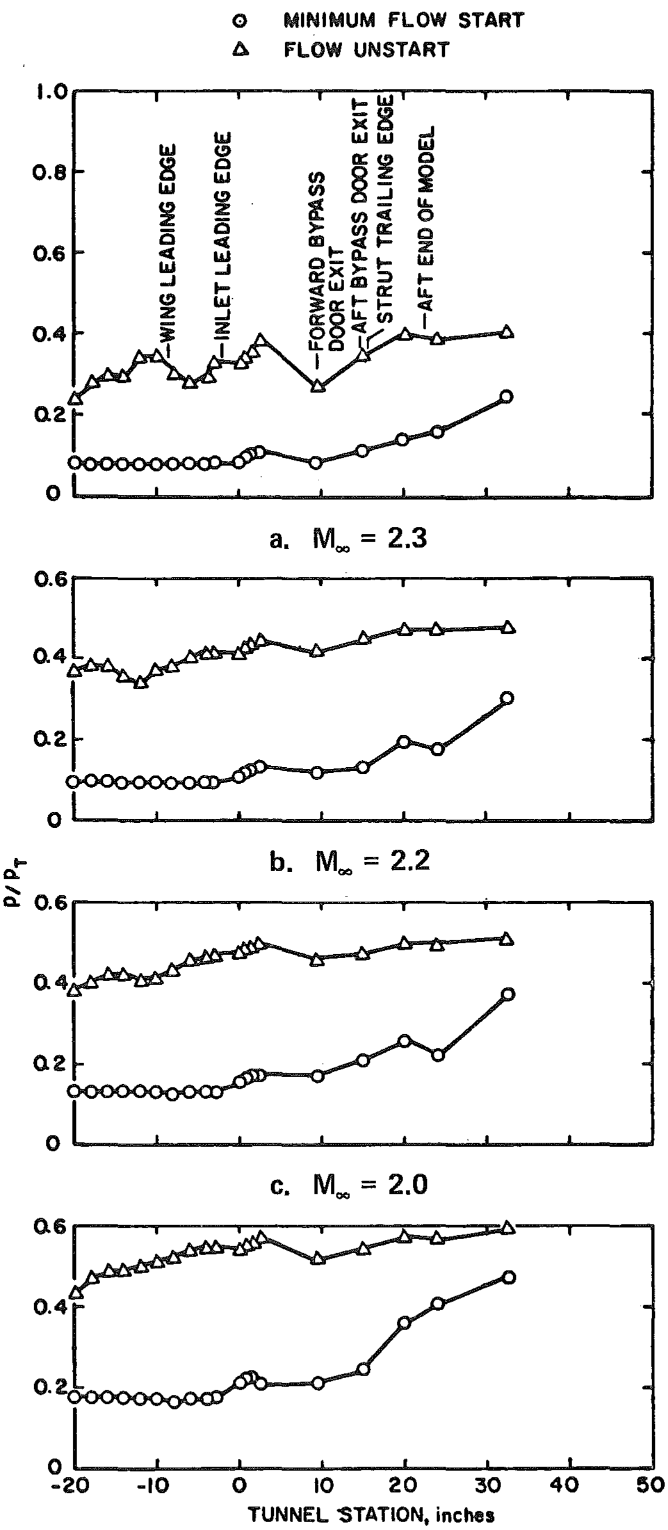


Fig. 20 Typical Tunnel 1S Wall Static Pressure Distributions for Nacelle Configuration II



d. M_∞ = 1.8

Fig. 21 Typical Tunnel 1S Wall Static Pressure Distributions for Nacelle Configuration I

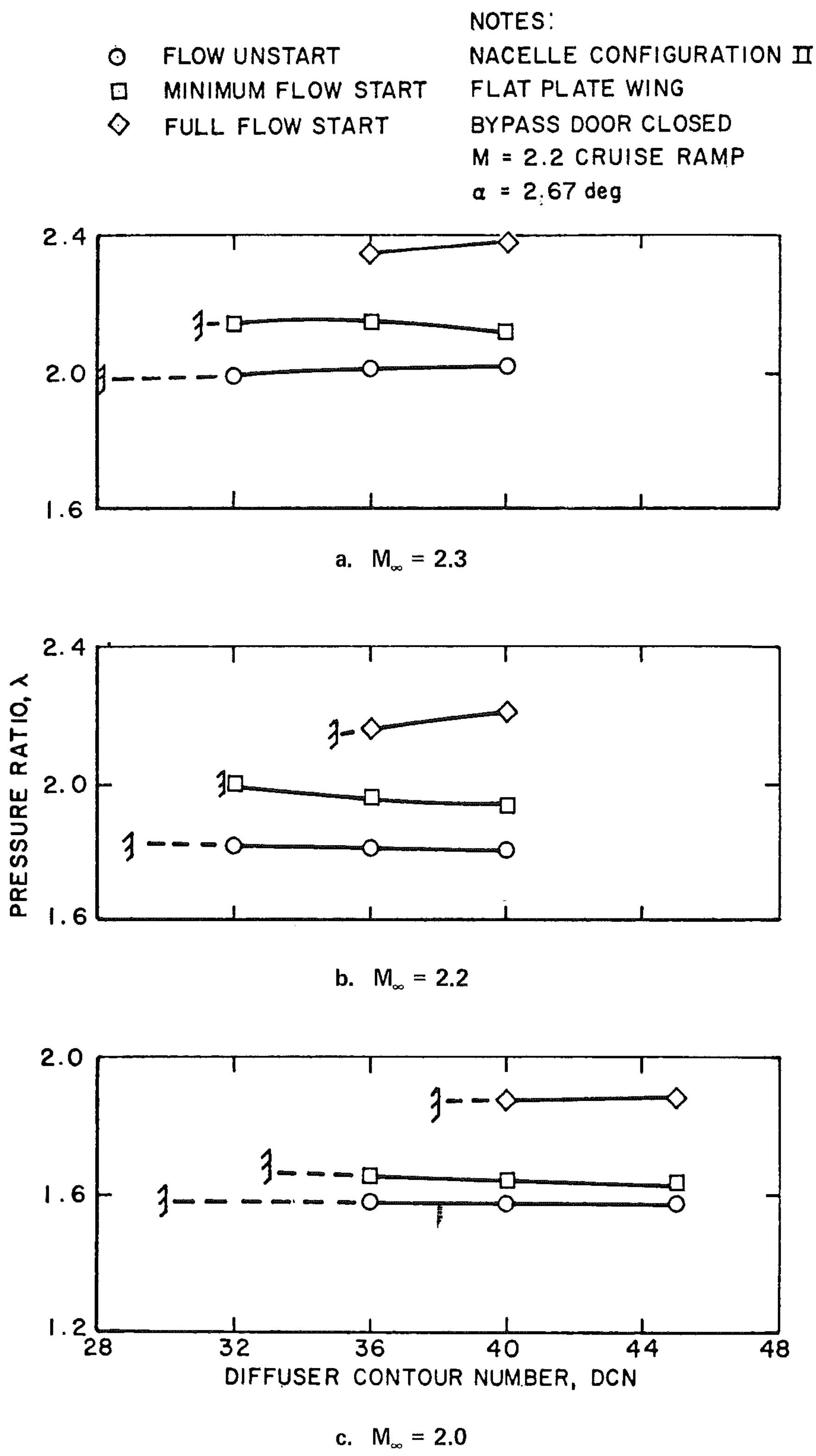


Fig. 22 Typical Effect of Diffuser Position on Pressure Ratio Requirements for Starting and Unstarting

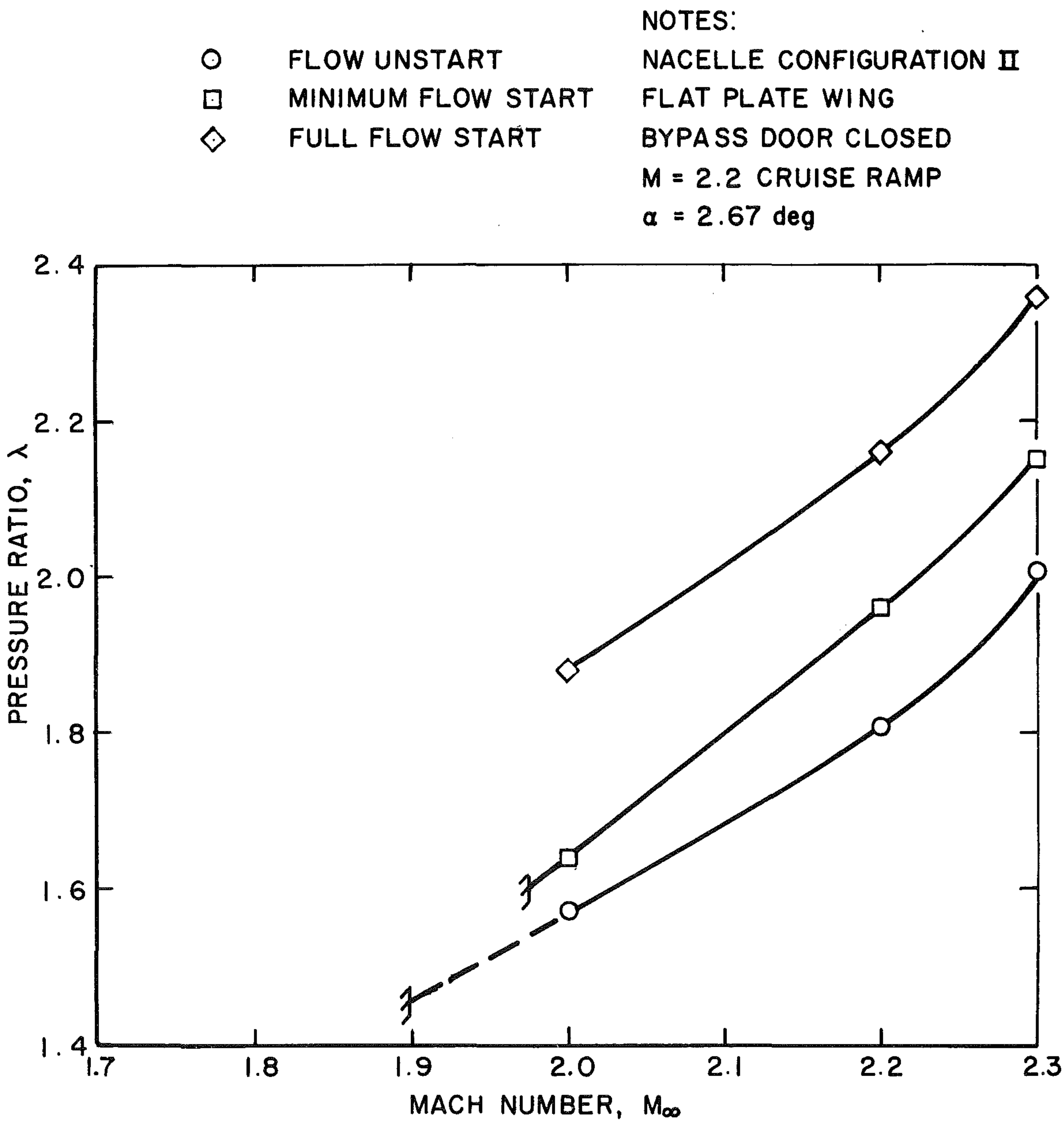


Fig. 23 Typical Effect of Mach Number on Pressure Ratio Requirements for Starting and Unstarting

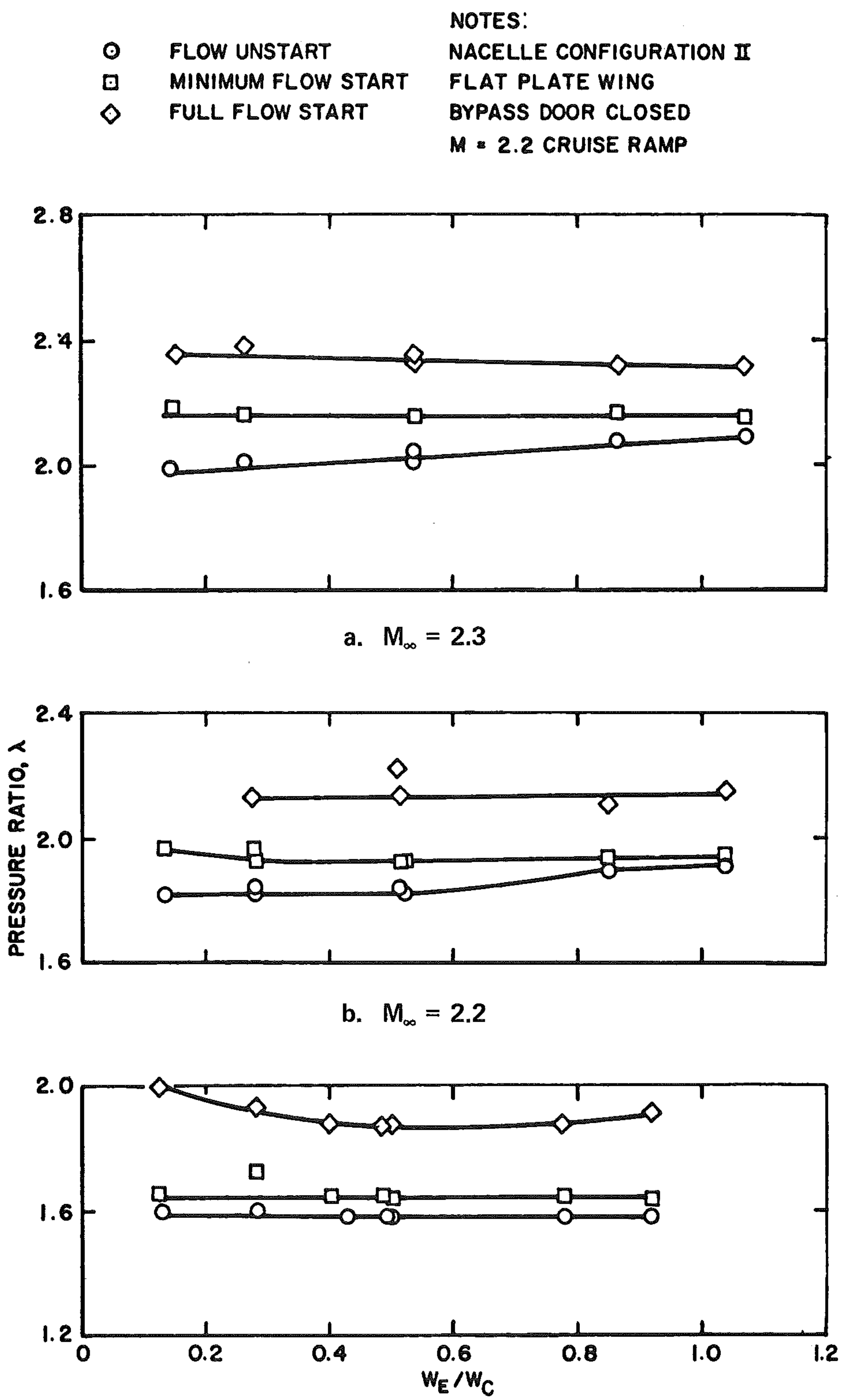


Fig. 24 Effect of Inlet Mass Flow Ratio on Minimum Pressure Ratio for Starting and Unstarting

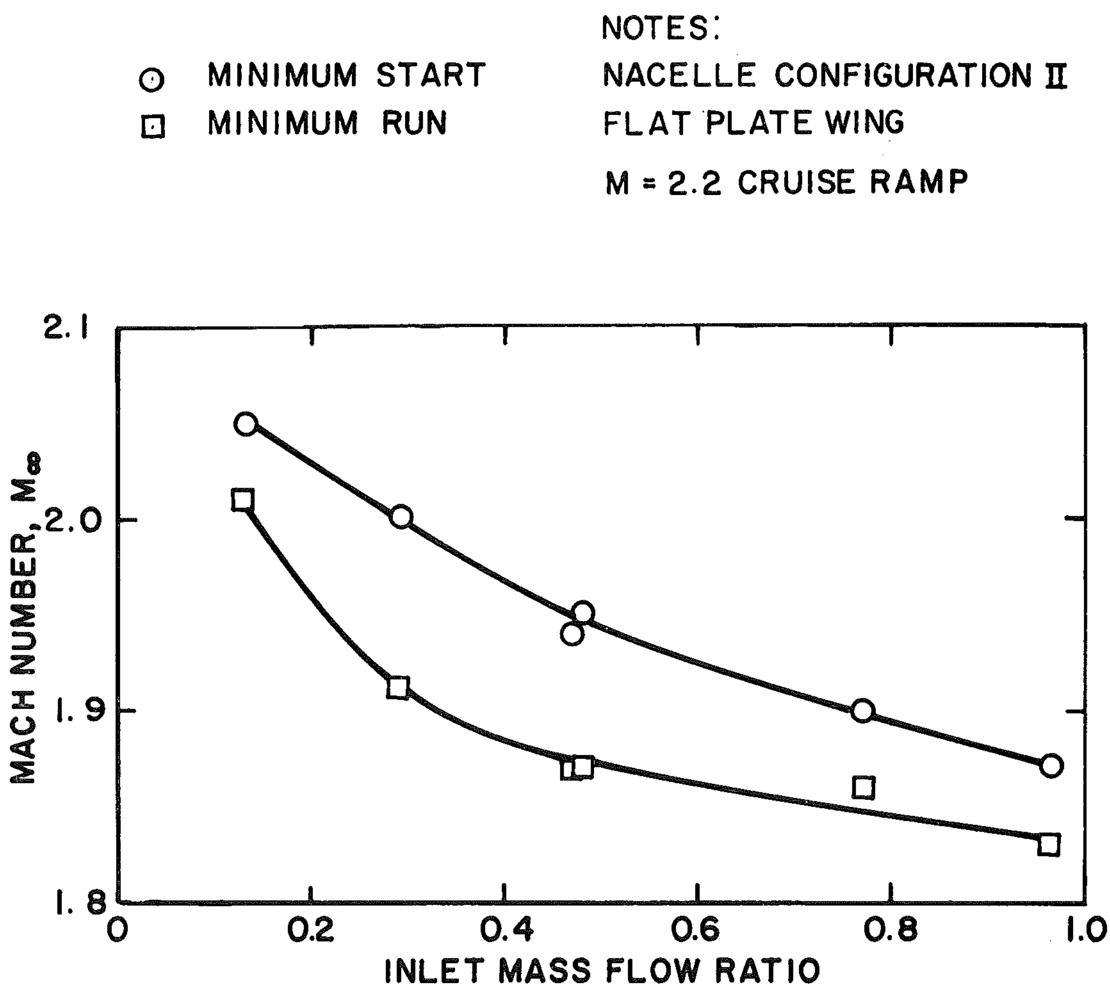
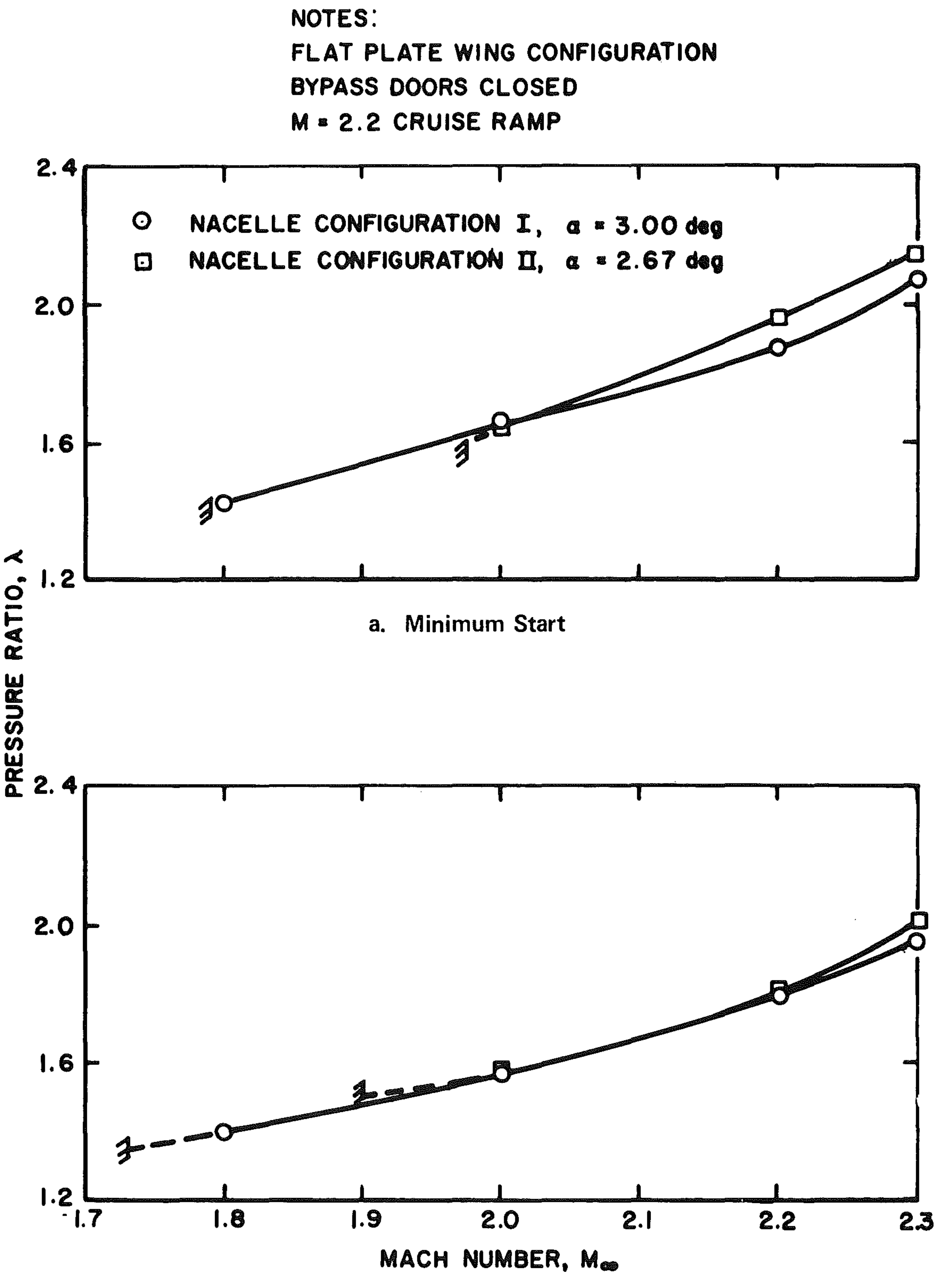
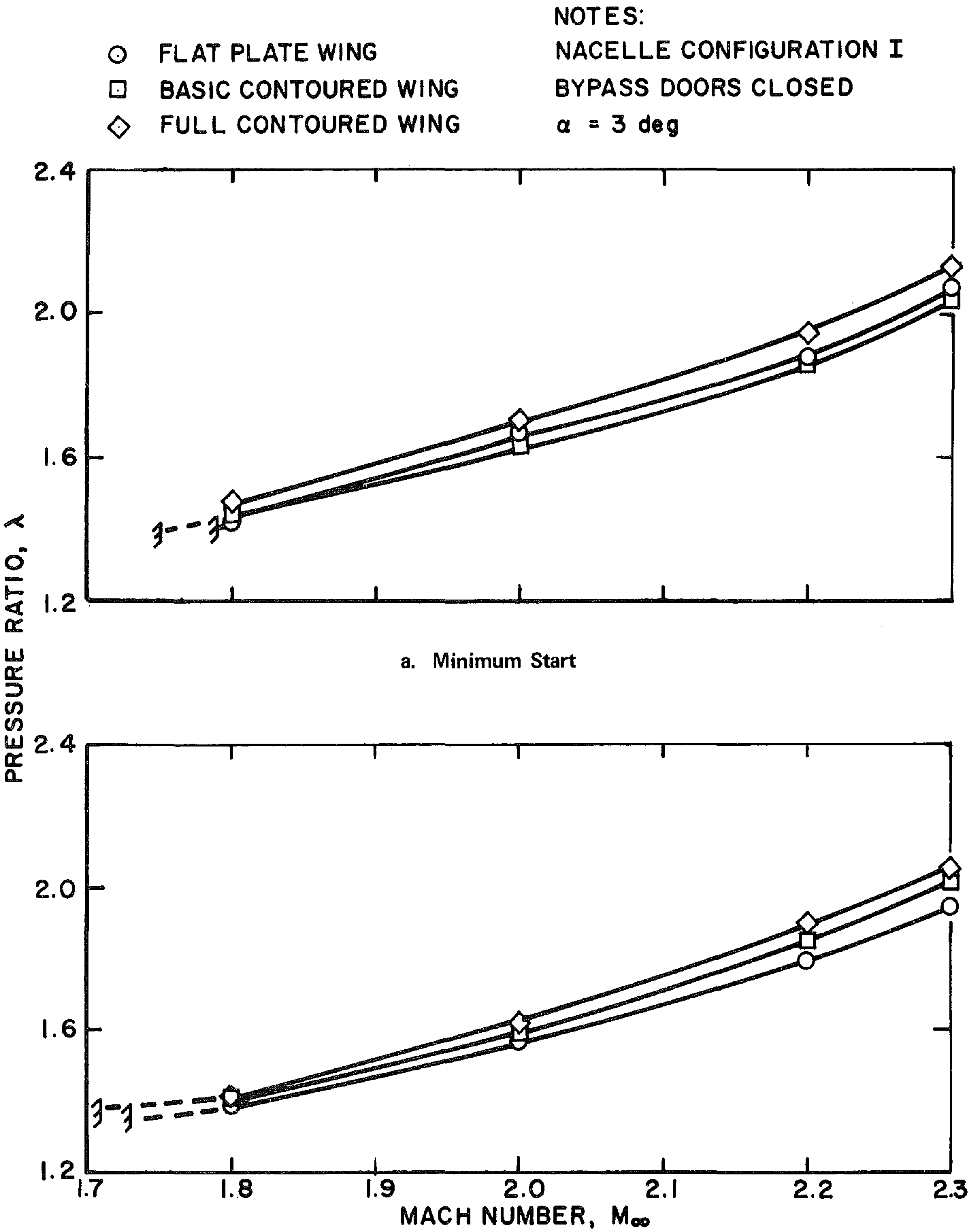


Fig. 25 Effect of Inlet Mass Flow Ratio on Minimum Starting and Running Mach Number



b. Minimum Run

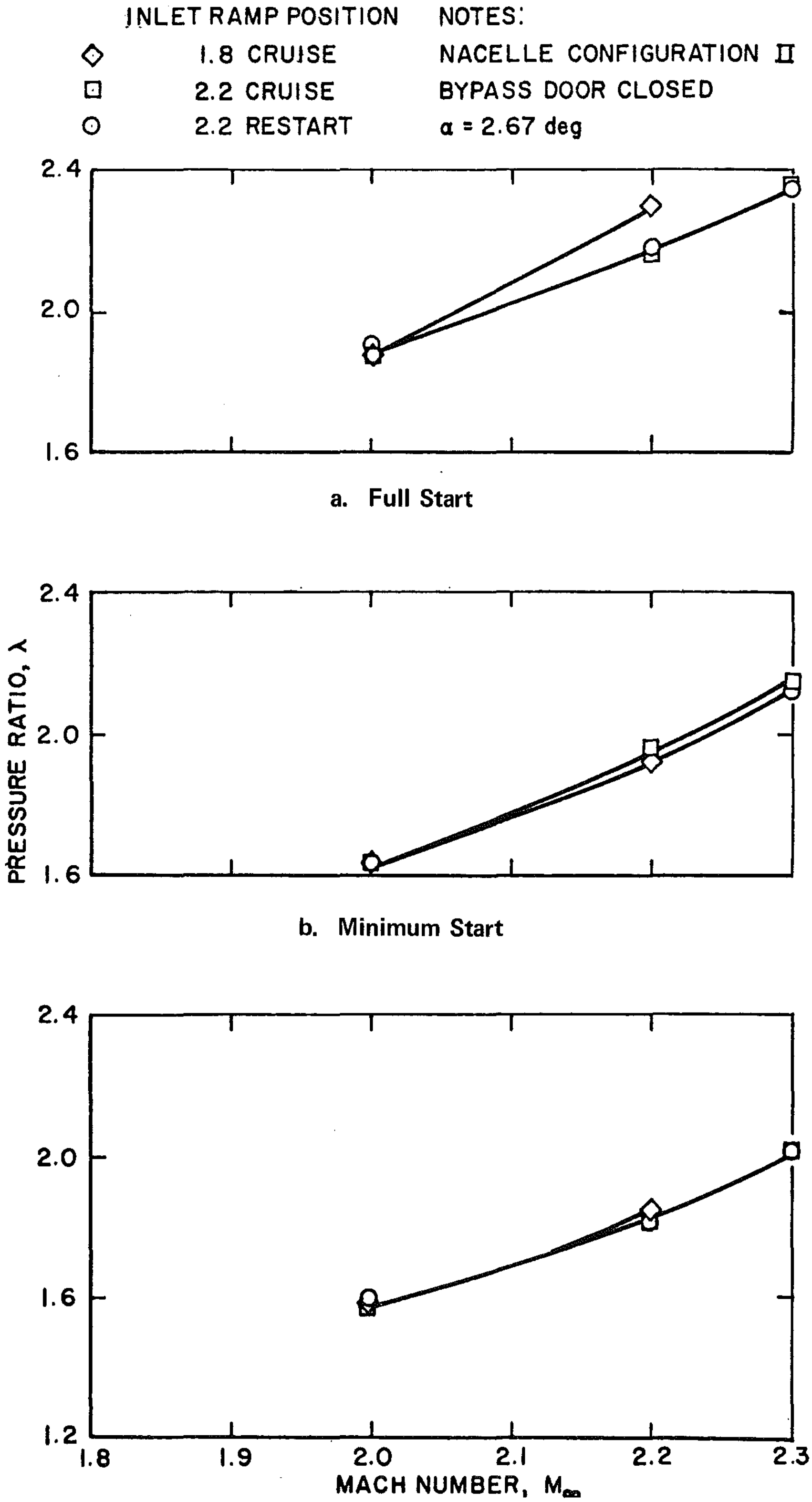
Fig. 26 Effect of Nacelle Configuration on Minimum Pressure Ratio for Starting and Unstarting



a. Minimum Start

b. Minimum Run

Fig. 27 Effect of Wing Configuration on Minimum Pressure Ratio for Starting and Unstarting



a. Full Start

b. Minimum Start

c. Minimum Run

Fig. 28 Effect of Inlet Ramp Position on Minimum Pressure Ratio Starting and Unstarting

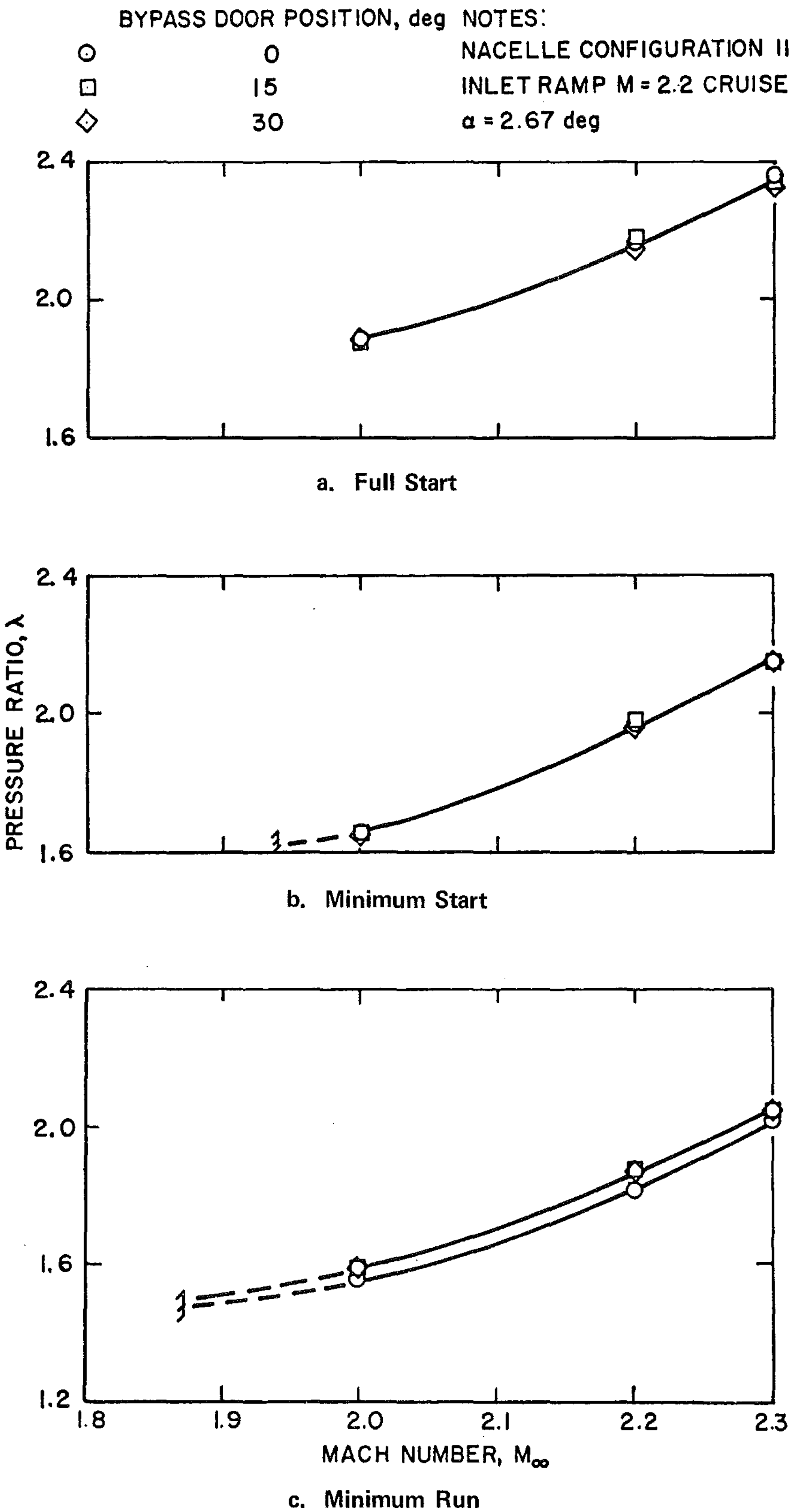


Fig. 29 Effect of Bypass Door Position on Minimum Pressure Ratio for Starting and Unstarting

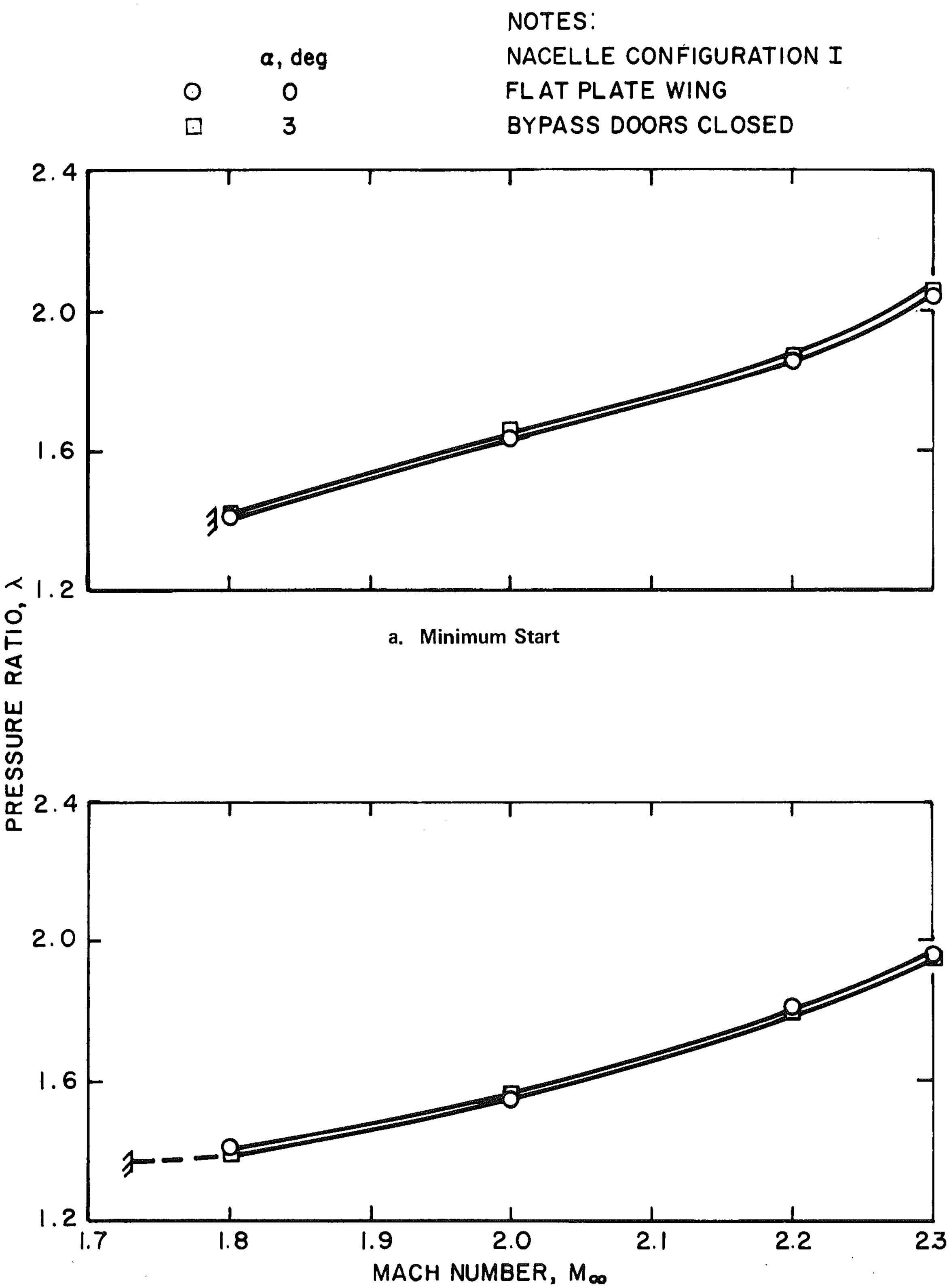


Fig. 30 Effect of Angle of Attack on Minimum Pressure Ratio for Starting and Unstarting

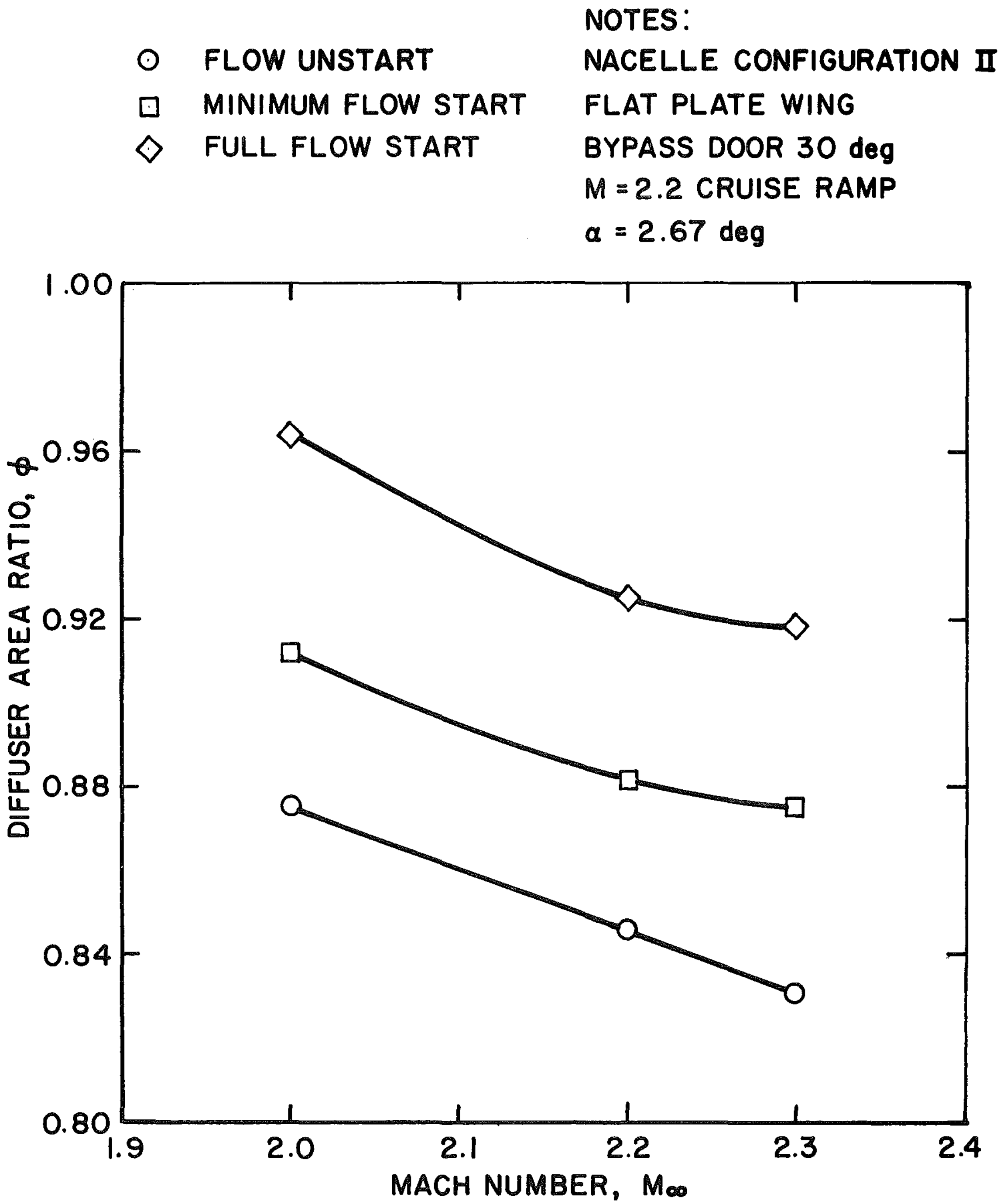


Fig. 31 Minimum Diffuser Area Ratios for Starting and Unstarting for the Full-Scale B-1 Test in Tunnel 16S

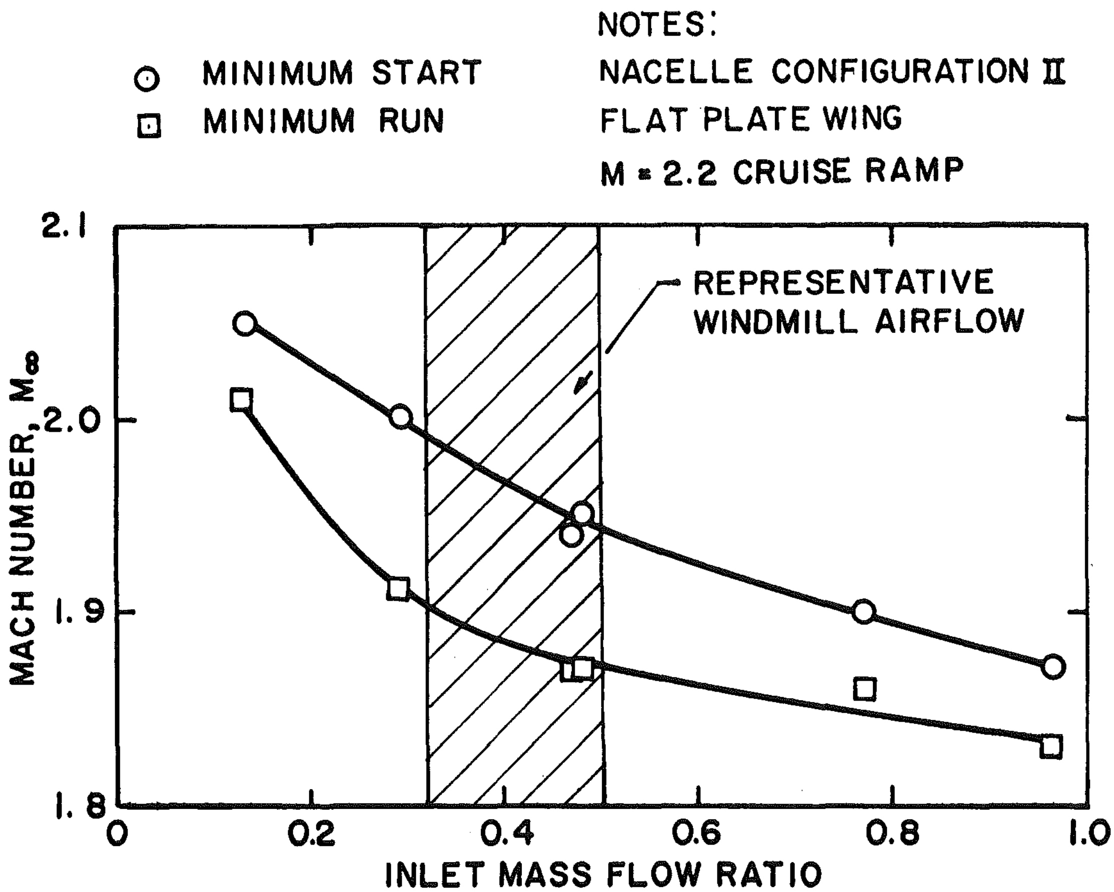
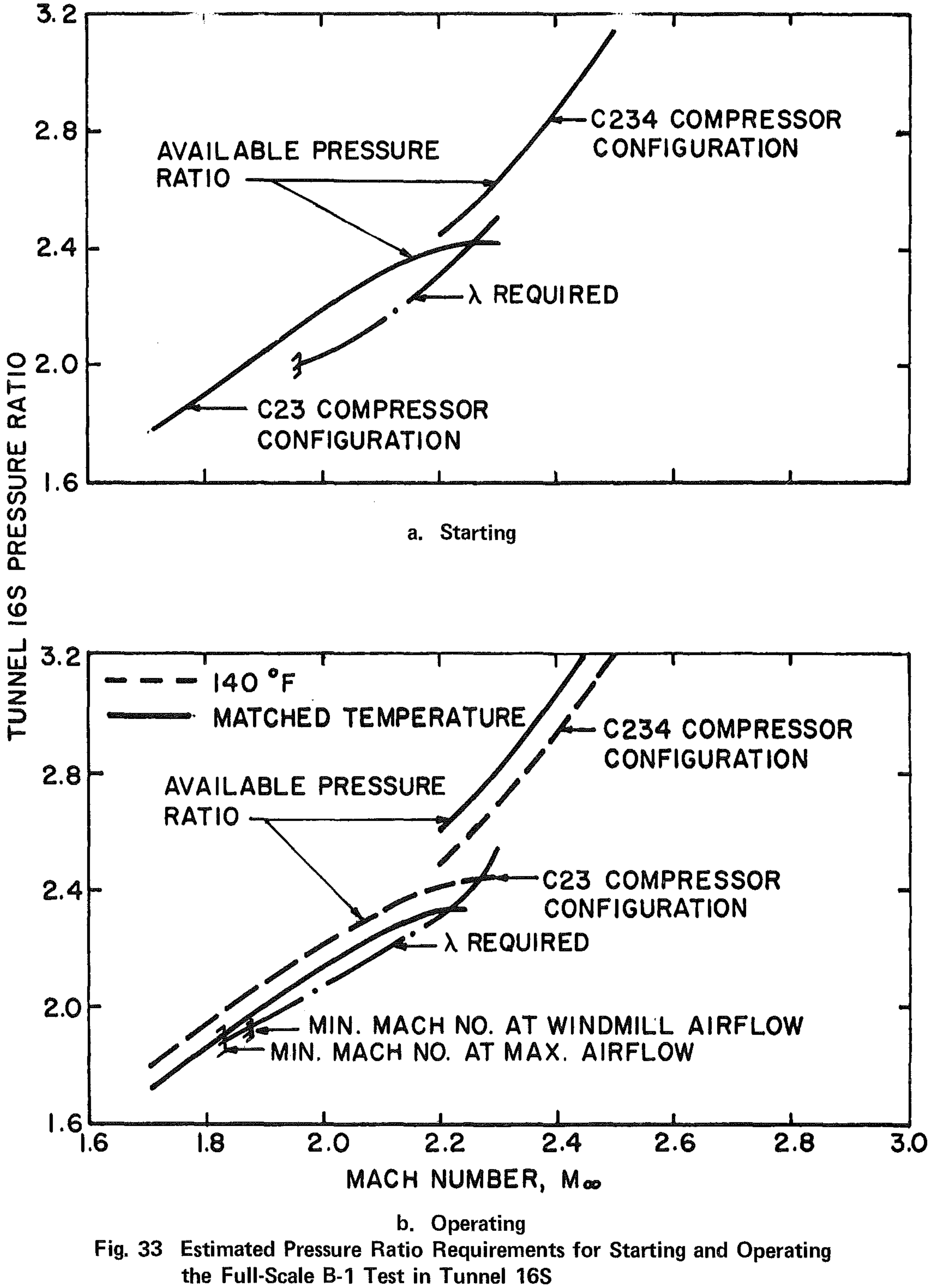


Fig. 32 Minimum Mach Numbers for Starting and Operating for the Full-Scale B-1 Test in Tunnel 16S



b. Operating

Fig. 33 Estimated Pressure Ratio Requirements for Starting and Operating the Full-Scale B-1 Test in Tunnel 16S

TABLE I
TUNNEL 16T ESTIMATED OPERATING PRESSURE RATIOS AND TUNNEL 1T NOMINAL PRESSURE RATIOS

Mach Number	Tunnel 16T Estimated Operating λ	Tunnel 1T λ *
0.55	1.120	1.10
0.70	1.160	1.15
0.85	1.230	1.23
0.90	1.270	1.27
1.10	1.420	1.40
1.20	1.470	1.40
1.30	1.485	1.40

APPENDIX III
AVAILABLE PERFORMANCE IN TUNNELS 16T AND 16S

III.1 Tunnel 16T

The 16-ft transonic tunnel (Propulsion Wind Tunnel, Transonic [16T]) is a continuous-flow, closed-circuit tunnel capable of operation over a Mach number range from 0.2 to 1.6. A detailed description of this tunnel and its capabilities is given in Ref. 5. A layout showing the arrangement of Tunnel 16T is presented in Fig. III-1.

Mach numbers in Tunnel 16T are set in a similar manner to that described for Tunnel 1T in Section III. Propulsion engine scavenging and tunnel auxiliary weight flow may be obtained with the Engine Test Facility (ETF) exhauster plant and the PWT Plenum Evacuation System (PES).

The PWT PES is composed of two identical plants, each with six axial-flow compressors. Tunnel ducting allows the plant to be split if required for two different purposes. A typical auxiliary weight flow capacity of the PES is presented in Fig. III-2. The PES performance varies with the engine scavenging requirements, the amount of makeup air that is processed by the PES, and with test conditions. For tunnel operation with stagnation pressure above ambient, the makeup air, which replenishes that removed through the scavenging system, must be processed by the PES.

Estimates for the full-scale B-1 test indicate that for $M_\infty \geq 1.0$ all of the ETF exhausters and one-half of the capacity of the PES will be required for the scavenging of the engine exhaust products. Only one-half of the PES, therefore, will be available to provide tunnel auxiliary weight flow for $M_\infty \geq 1.0$. For $M_\infty < 1.0$, the estimates indicate that only the ETF plant is required for engine scavenging. Therefore, for $M_\infty < 1.0$, full PES capacity is available to provide tunnel auxiliary weight flow. In addition to auxiliary weight flow capacity, the performance available in Tunnel 16T for the full-scale test is also limited by the availability of test facility utilities, the cooling water temperature, which varies with the month of the year, and power limits on the main drive and PES compressor systems. The minimum altitudes estimated to be available in Tunnel 16T for the B-1 full-scale test are shown in Fig. III-3. A recommended operating line, which will provide for simplier tunnel operation and avoid most major scheduling conflicts, is also presented in Fig. III-3. Since the B-1 test is scheduled for a "warm" month, the minimum stagnation temperature estimated to be available

in Tunnel 16T is 110°F. For this temperature, a temperature mismatch from about 0 to 44° and 30 to 44° exists for the minimum and recommended operating lines, respectively.

The tunnel auxiliary weight flow capacity provided by the PWT PES for the full-scale test in Tunnel 16T is presented in Fig. III-4. The data presented were computed for the minimum and recommended operating lines shown in Fig. III-3. For the minimum operating line, make-up airflow must be processed by the PES, and PES power limits also decrease the available capacity at $M_\infty < 0.85$.

Data obtained during the F-15 full-scale test in Tunnel 16T indicate that the required auxiliary weight flows were about 60 percent higher than the requirements indicated by the Tunnel 1T blockage test (Ref. 4). To obtain estimates of the available performance for the full-scale B-1 test in Tunnel 16T, therefore, the Tunnel 1T auxiliary weight flow requirements should be increased by 60 percent.

III.2 Tunnel 16S

The 16-ft supersonic tunnel (Propulsion Wind Tunnel, Supersonic [16S]) is a continuous-flow, closed-circuit tunnel designed to operate within a Mach number range from 1.5 to 6.0. A detailed description of this tunnel and its capabilities is given in Ref. 5. A layout showing the arrangement of Tunnel 16S is presented in Fig. III-1.

The Tunnel 16S main compressor plant consists of four axial-flow compressors designated C2 through C5. The system can be operated with configurations of one to four compressors in series. The aerodynamic performance of the PWT main compressor as reported in Ref. 9 was used to obtain results presented in this appendix. The volume flow capacity of the main compressors can be augmented with the PWT PES and the exhauster plant of the Engine Test Facility (ETF). These auxiliary compressor systems are also utilized to scavenge test engine exhaust products and to provide tunnel air exchange. Because of the manner in which the air removed through the scavenging system is replaced in the tunnel, that flow also augments, but to a lesser degree, the capacity of the main compressor.

It is beyond the capability of the PWT and ETF exhauster plants to set a scavenge pressure equivalent to stream static pressure in Tunnel 16S. The complete operating performance of the full-scale B-1 test engine is not yet known. Assuming that a scavenge duct pressure of 430 psfa is acceptable, it is estimated that only the ETF exhauster plant will be required for engine scavenging. This will allow both incre-

ments of PES to be utilized to augment the main tunnel compressor and tunnel air exchange requirements.

The available pressure ratios in Tunnel 16S for starting and operating for the full-scale B-1 test are presented in Fig. III-5. Since the B-1 is scheduled for a "warm" month, a compressor inlet temperature of 100°F was utilized to calculate the performance shown. The operating performance was calculated for stagnation temperatures representative of "cold flow" and matched temperature testing. In addition, the calculations were made assuming about one-half of the capacity of PES and that of the exhauster plant used for scavenging provided main compressor augmentation.

The available pressure ratios in Tunnel 16S vary with the period of the year because of variation of the temperature of the AEDC cooling water. Typical values of the cooling water temperature are given in Ref. 5. The tunnel occupancy date for the full-scale B-1 test has been scheduled during a "warm" month. Should the test be conducted during a "cold" month, the performance shown in Fig. III-5 will provide conservative estimates of the available performance for the full-scale test.

The pressure ratio data obtained in Tunnel 1S cannot be applied directly to Tunnel 16S. Previous test results, reported in Ref. 3, indicate that the Tunnel 16S pressure ratio requirements exceed those for Tunnel 1S. Data obtained during the F-15 full-scale test indicate that the pressure ratio relationship between Tunnels 16S and 1S, which was reported in Ref. 3, should be modified. The increment of pressure between Tunnels 16S and 1S, which is to be utilized to evaluate the tunnel performance available for the full-scale test, is presented in Fig. III-6.

The minimum altitude line estimated to be available in Tunnel 16S for the B-1 Full-Scale Test is shown in Fig. III-7. A recommended operating line, which will provide for simpler tunnel operation and avoid most major scheduling conflicts, is also presented in Fig. III-7.

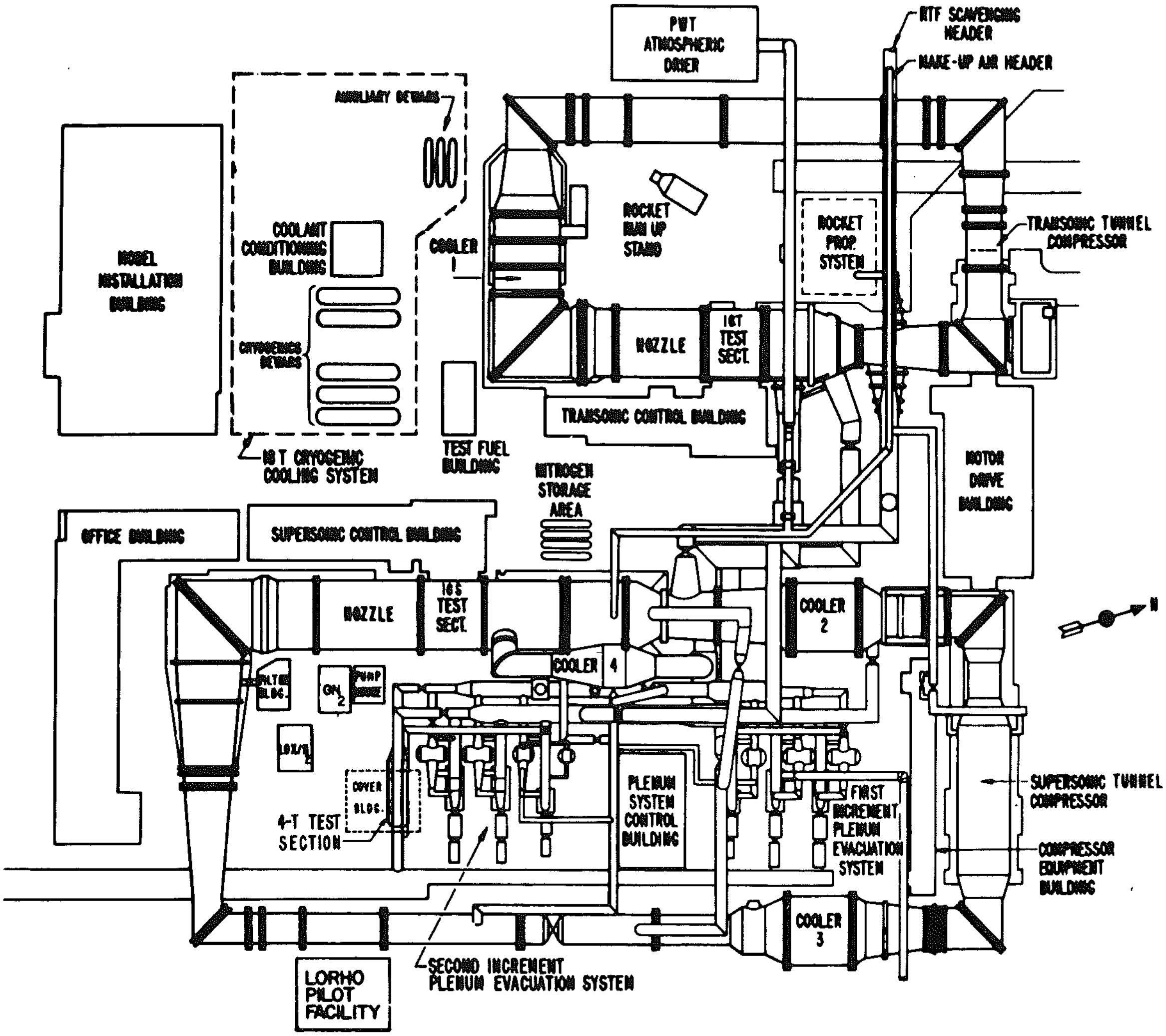


Fig. III-1 General Arrangement of the PWT 16-Ft Tunnels

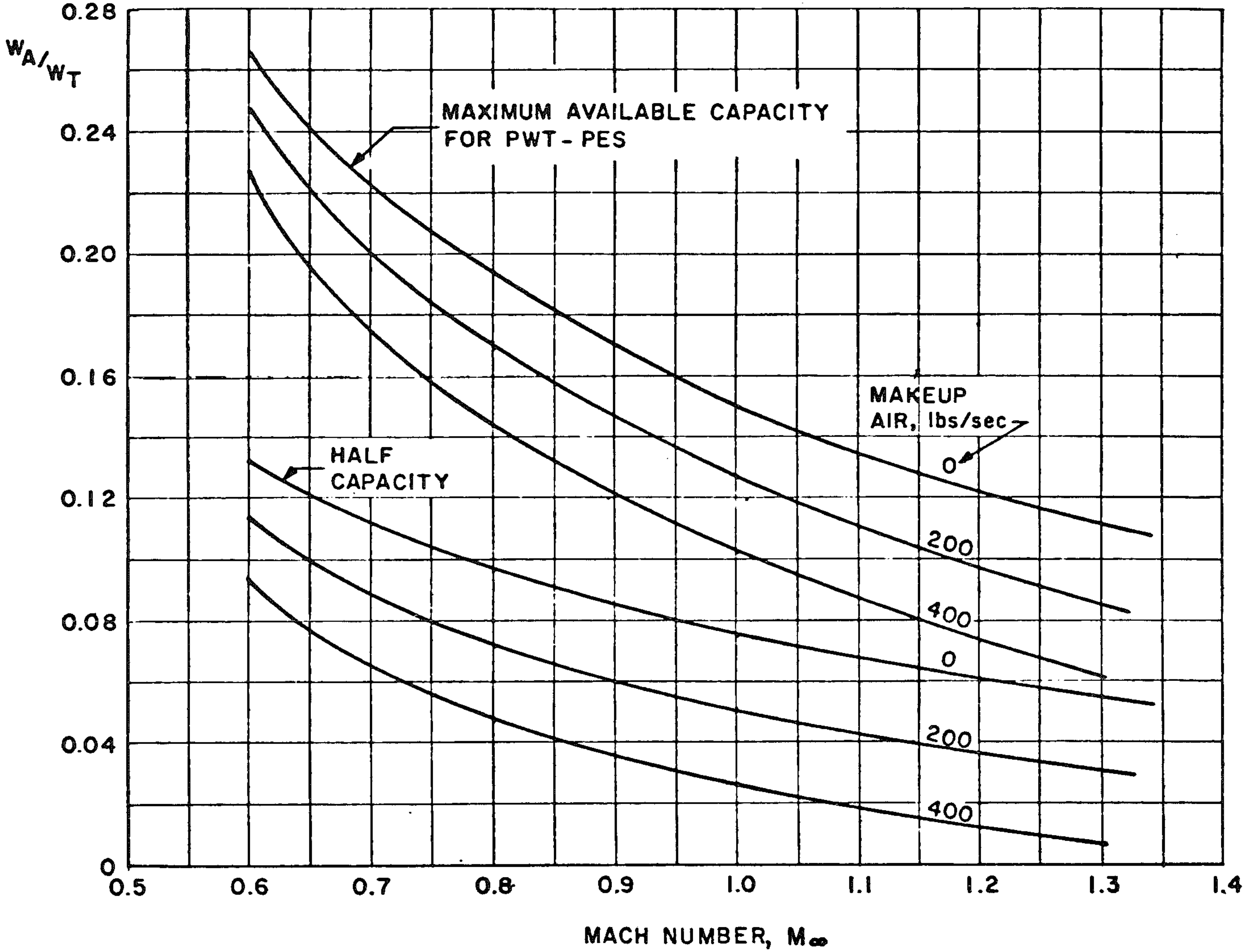


Fig. III-2 Typical Performance of the PWT Plenum Evacuation System

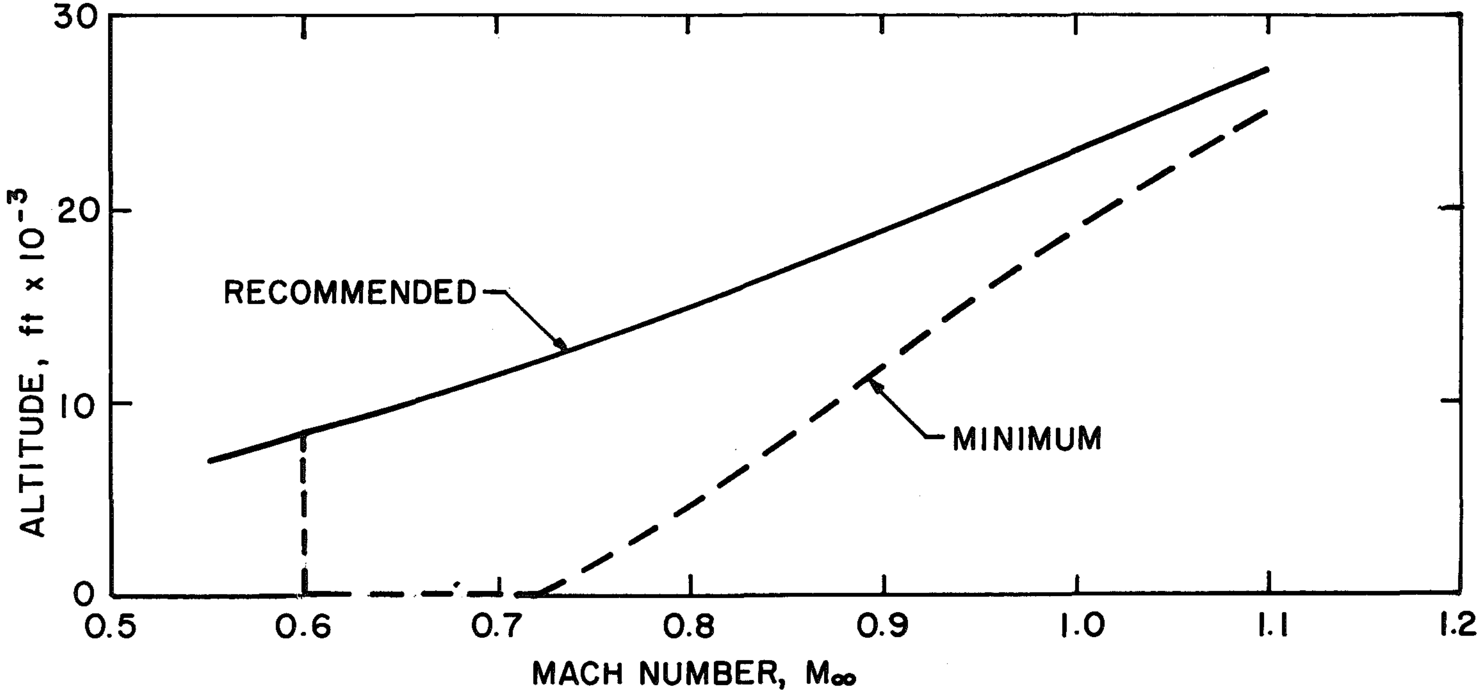


Fig. III-3 Recommended and Minimum Operating Lines for the Full-Scale B-1 Test in Tunnel 16T

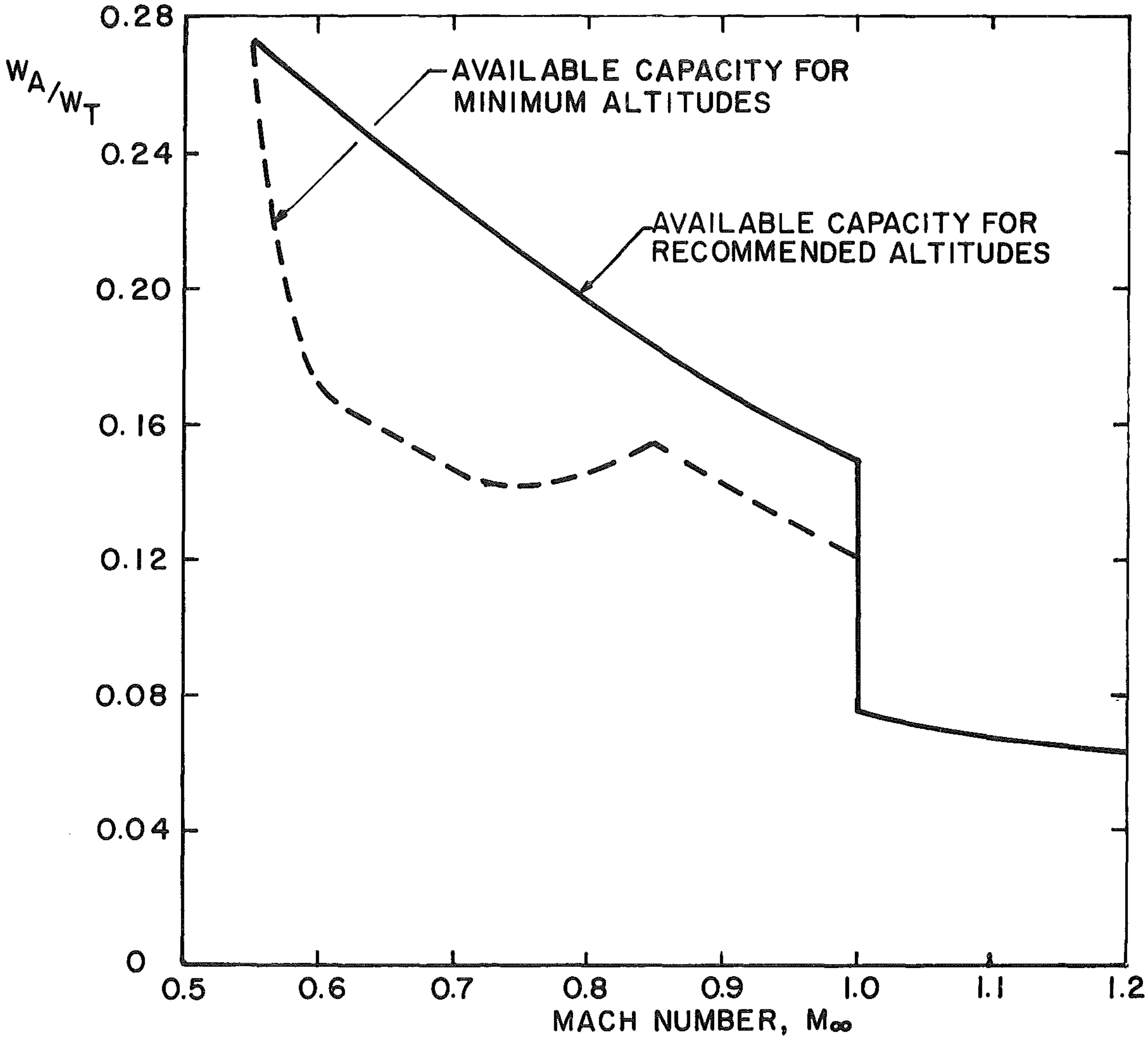
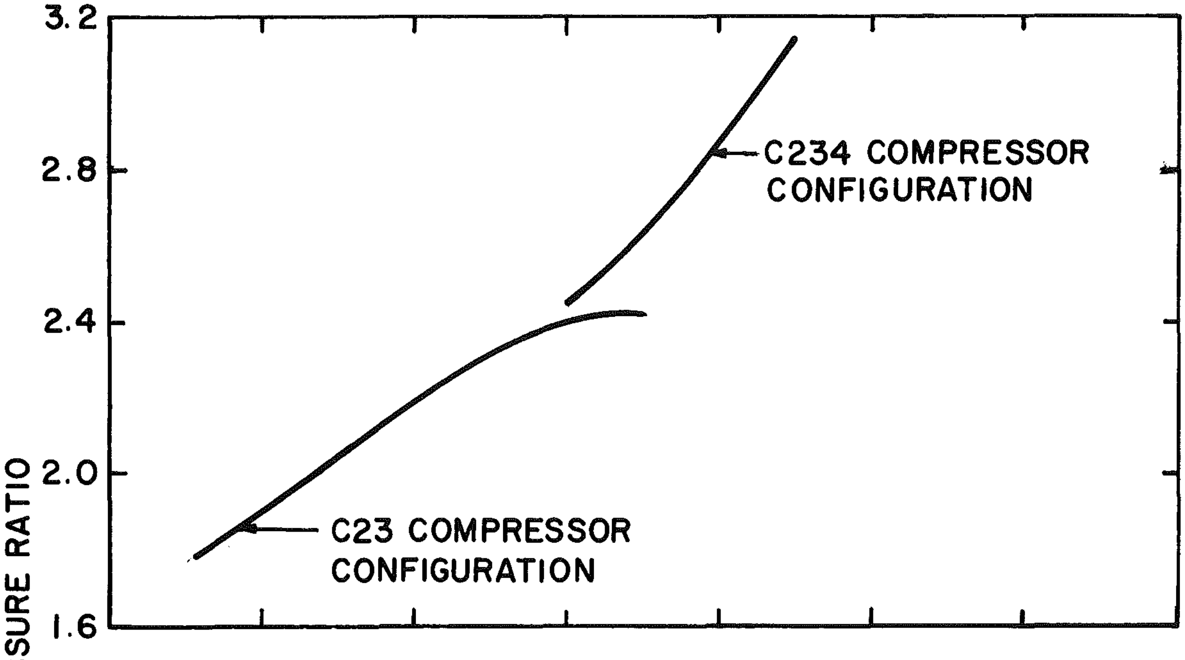
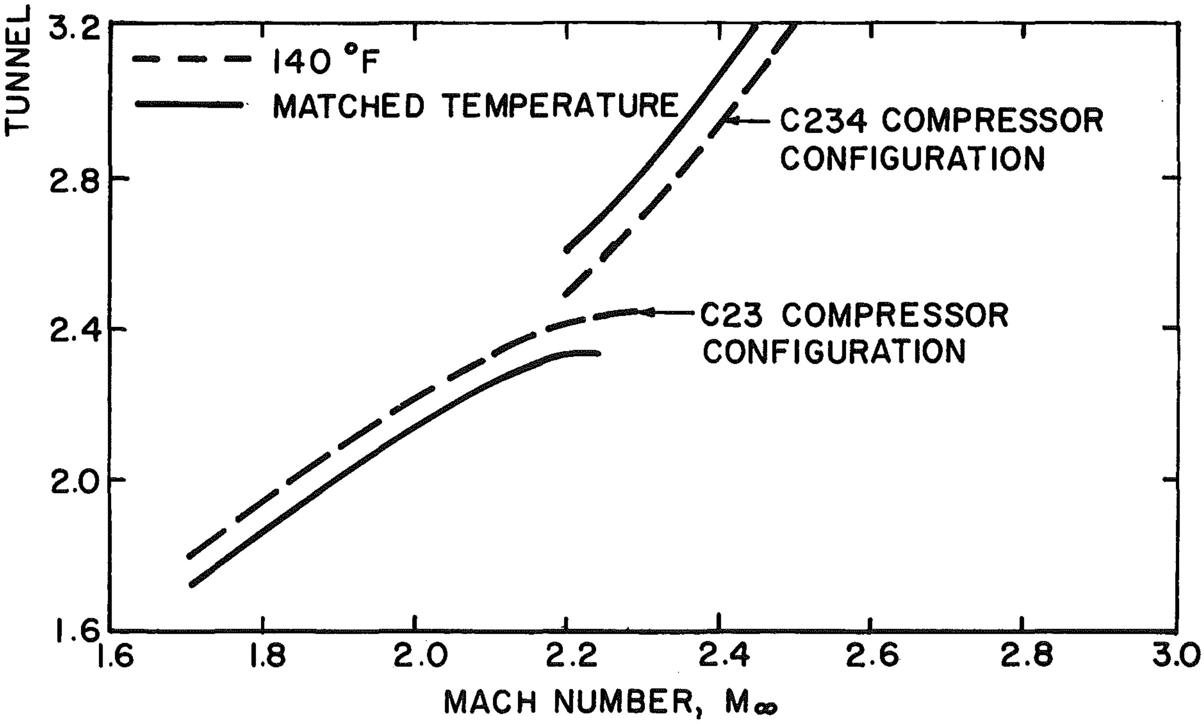


Fig. III-4 Estimated Performance of the PWT Plenum Evacuation System for the Full-Scale B-1 Test in Tunnel 16T

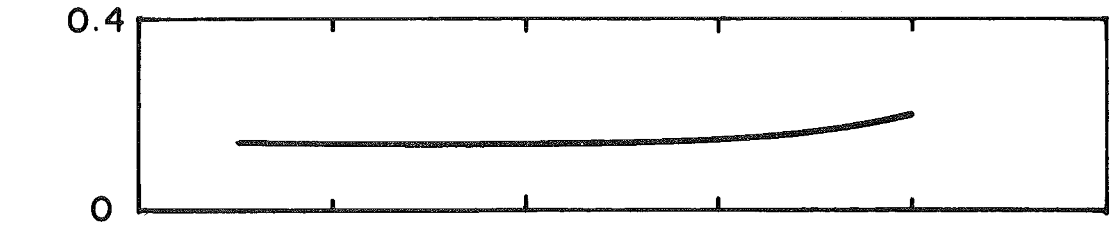


a. Starting

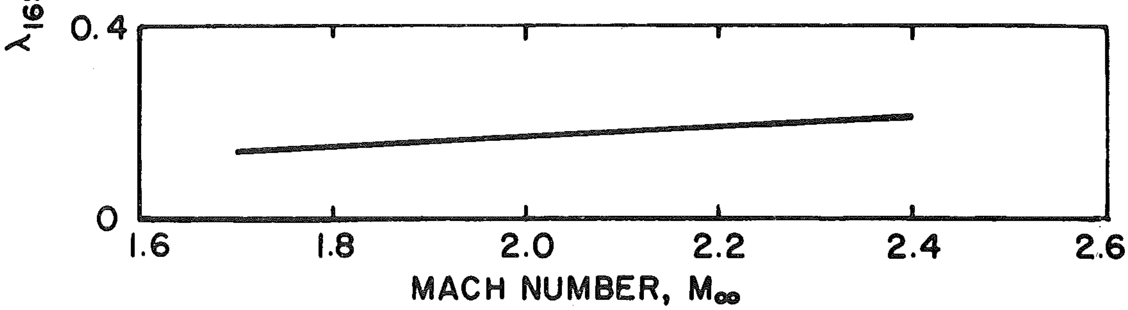


b. Operating

Fig. III-5 Pressure Ratio Available for Starting and Operating for the Full-Scale B-1 Test in Tunnel 16S



a. Starting



b. Unstarting

Fig. III-6 Estimated Increment of Pressure Ratio Between Tunnels 16S and 1S

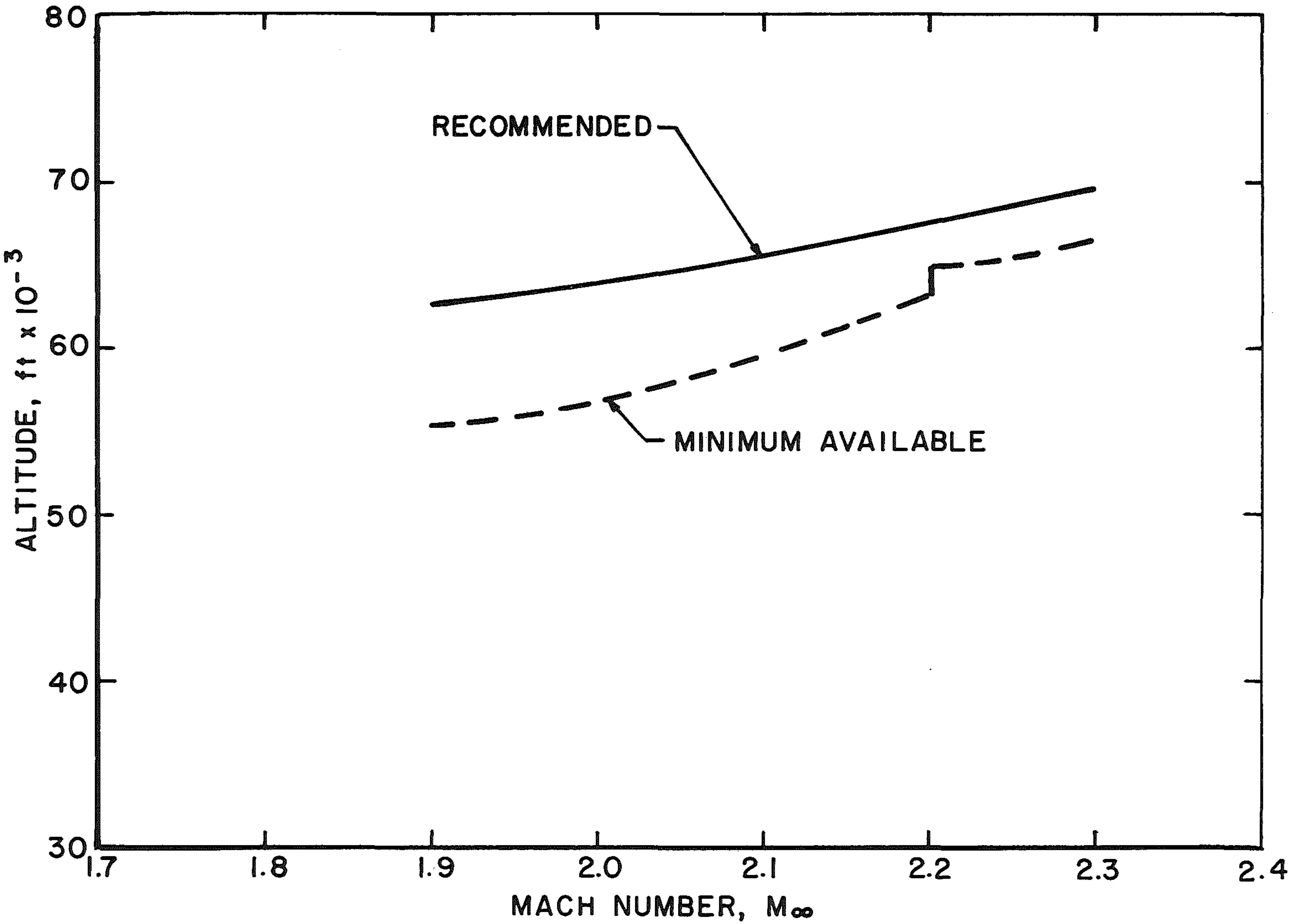


Fig. III-7 Tunnel 16S Operating Range for the Full-Scale B-1 Test in Tunnel 16S

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13. ABSTRACT

Tests were conducted in the 1-ft Aerodynamic Wind Tunnels (1T and 1S) of the Propulsion Wind Tunnel Facility to obtain estimates of the performance available for the full-scale B-1 inlet/engine tests in the 16-ft Propulsion Wind Tunnels (16T and 16S). Data were obtained with two nacelle configurations and four wing configurations. The maximum test section blockage was 17 percent. Data were obtained at Mach numbers from 0.55 to 1.30 and from 1.71 to 2.30. The tunnel performance for each configuration was evaluated relative to the others and with regard to the capabilities of the 16-ft tunnels. The results of these tests indicate that the available tunnel performance is significantly compromised with the nacelle configuration which has been selected for the full-scale test. The maximum Mach number estimated to be available for the full-scale test in Tunnel 16T is 1.0. To obtain a full range of engine operating points, however, testing should be restricted to $M \leq 0.90$. The estimated starting and operating pressure ratio requirements for the full-scale B-1 test are within the Tunnel 16S capability. The minimum starting Mach number estimated to be available for the full-scale B-1 test in Tunnel 16S is 1.96. The minimum operating Mach numbers estimated to be available for the full-scale test are 1.83 at full inlet airflow and 1.88 at windmill airflow.

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engine inlets						
transonic wind tunnels						
supersonic wind tunnels						
blocking						
performance						
aerodynamic configurations						
model tests						

1. Air inlets -- Supersonic flow
2. " " -- Transonic "
3. " " -- Blockage

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